EXPERIMENTAL STUDY ON SPIRALLY CONFINED PLAIN AND FIBROUS CONCRETE UNDER AXIAL LOADING

by

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DEPARTMENT OF NUCLEAR ENGINEERING AND TECHNOLOGY
INDIAN INSTITUTE OF TECHNOLOGY KANPUR

JANUARY, 1990

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A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

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to

Parents

and Teachers

CERTIFICATE

This is to certify that the work presented in this thesis entitled

" EXPERIMENTAL STUDY ON SPIRALLY CONFINED PLAIN AND FIBROUS CONCRETE UNDER AXAIL LOADING "

by Gundlapalli Prabhakar has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

I.I.T.,Kanpur.

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(gundlapalli prabhakar)

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LIST OF SYMBOLS and ABBREVIATIONS.

Ag: gross area of the section

Ac: area of the core of the helically/hoop reinforced specimen measured to the out side of the helix/hoop.

fck: charecteristic compressive strength of concrete

fy: charecterstic compressive strength of the helical reinforcement but not exceeding 415 MPa.

Vs: volume of the spiral

Vc: volume of the core

Vh: volume of the hoops

f'cc: axial compressive strength of confined concrete

f'c: axial compressive strength of unconfined concrete

fl: lateral confining pressure

P.C.C.: plain cement concrete

R.C.C.: reinforced cement concrete

P.S.C.: pre-stressed concrete

F.R.C.: fiber reinforced concrete

A.S.C.E.: American Society of Civil Engineers

A.C.I.: American Concrete Institute

I.S.: Indian Standards

ABSTRACT

In the present work behavior of circular concrete specimens under axial loading is investigated experimentally, with varying amounts of spiral reinforcements conf rming to Indian and American codes of practice. Use of fibrous concrete with spiral is also studied. Failure mode of spirals and crushing of concrete are observed. Review of IS code provisions for helical reinforcements is suggested. Addition of fibers along with reduction in spiral volume showed ductile failure pattern and hence recommended.

KEYWORDS : Confinement, Ductility, Fibers, Spirals

1. I N T R O D U C T I O N.

1.0 HISTORY:

Concrete is used in structures primarily as a material subjected to compressive stresses induced as the effects of different types of loading conditions. For many years it was generally believed that R.C.C. does not posses good ductility properties. Stress-strain plot of cement concrete of different grades is illustrated in figure.1.1 [14]. The following important characteristics can be observed from this plot:

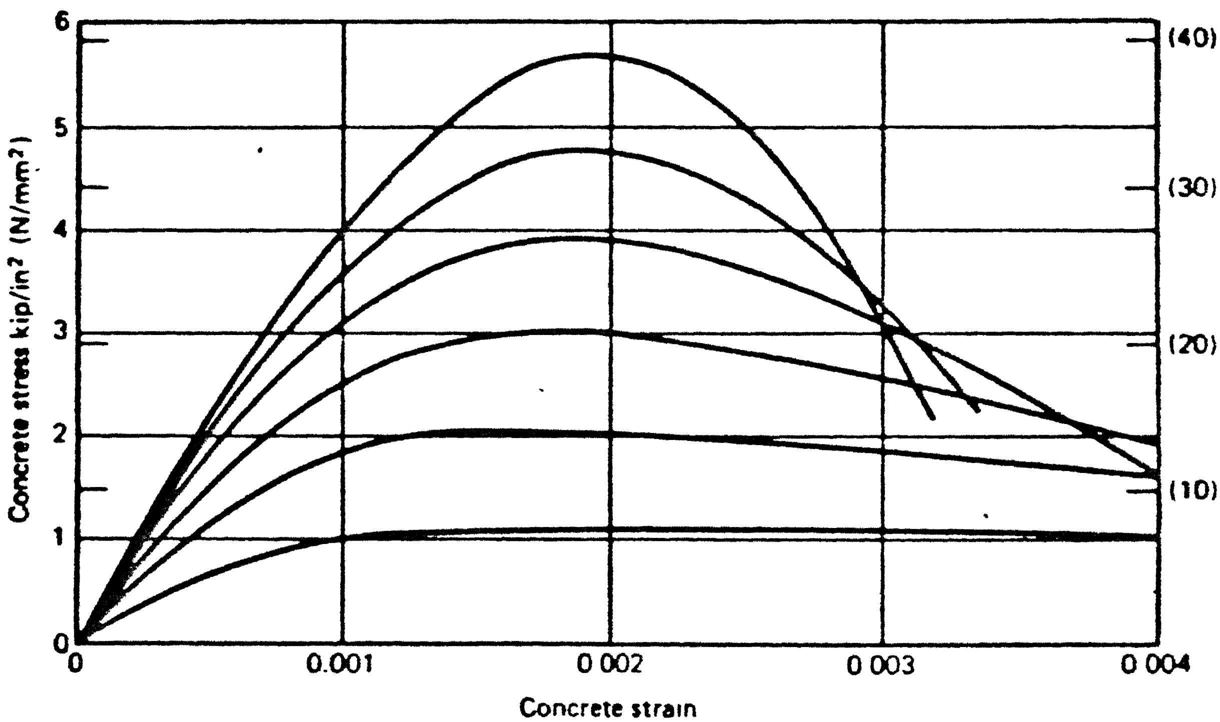
i> concrete shows predominantly brittle behavior.

ii> the slope of the curves and hence the modulus of elasticity increases with the increasing compressive strength.

iii> stress-strain relationship is nonlinear over most of the range

iv> maximum stress occurs at a strain of 0.002 and drops off rapidly at higher strain.

These above characteristics indicate that the failure of concrete members is generally governed by crushing of concrete due to it's limited ductility. So concrete members are reinforced with steel to improve their ductility properties. The design of steel reinforcements in concrete members subjected to earthquake and other dynamic, impact



Stress-strain curves for concrete cylinders loaded in uniaxial compression

Figure: 1.1 TYPICAL STRESS STRAIN CURVES OF CONCRETE.

and shock loads and forces should be critical from the view point of desired ductility considering the functional requirements of the structure under consideration.

From the past researches conducted, a few solutions to this problem have evolved [18]. For concrete members subjected to flexure the ductility properties can generally be improved by the use of under-reinforced sections, use of concrete of lower grades, better confinement in the compression regions or provision of fibers in the tensile region.

In the case of members subjected to axial compression with or without moments acting, this can be achieved by providing closely knit cage in the longitudinal and transverse directions and/or using closely spaced transverse reinforced reinforcement (either hoops and ties or spirals).

For compression members extensive research has been done regarding the concrete confinement by discrete transverse reinforcements in the form of circular, square or rectangular hoops or ties [6,10], but very few experimental data are available on the behavior of such members with spirals [7]. It is not possible to propose any design or analysis criteria based on the limited data available.

Various codes of practice for concrete design implicitly specify the minimum amount of transverse reinforcements in columns (detailed study is presented in Chapter 3) without any reference to the available ductility

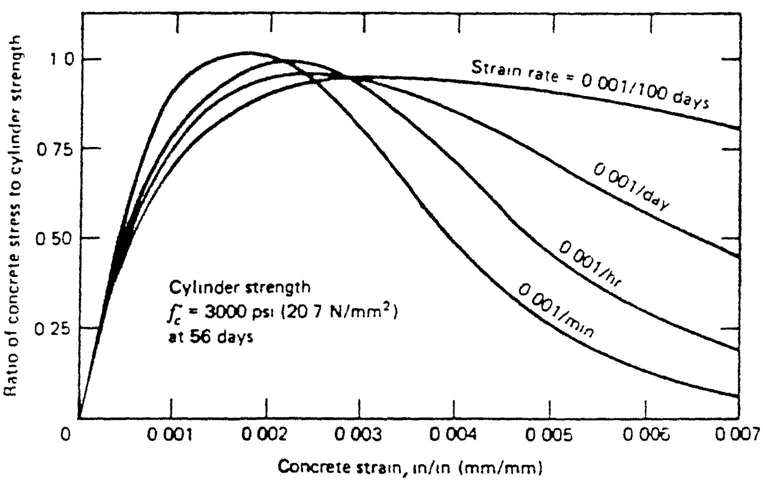


FIGURE 1.3 EFFECT OF RATE OF LOADING ON CONCRETE STRENGTH.

and the enhanced/increased compressive strength due to the confinement.

Endebrock [13] conducted tests of concrete cubes subjected to bi-axial and tri-axial loading conditions and observed that none of the existing failure theories could predict the failure of such cubes under tri-axial loads. He showed that uniform lateral (confining) pressure of magnitude equal to one-fifth of applied longitudinal pressure increased the compressive strength by four hundred and fifty percent; even larger increase was observed for higher confining pressures. Similar observations were also made by several investigators [6,7,10].

The increase of compressive strength due to lateral confining pressure has been illustrated in figure.1.2a,1.2b [14]. It has been observed that confining pressure increases ductility in addition to the strength increase in the longitudinal direction along with the reduction in the tendency for internal cracking and volume increase just prior to failure [19,18,16].

1.2 SCOPE OF THE PRESENT WORK:

To have better ductility of structures in seismic regions, strong column-weak girder design concept was studied in detail by Patnaik [21]. Though the tied and spiraled columns are equally effective within the normal range of service loads, when the structure is over loaded, spirally reinforced columns results in cracking and spalling

of concrete out side the spiral and is accompanied by large column shortening (ductile mode of failure) [20]. The load at which the outer shell spalls off is virtually independent of the amount of spiral present, a lighter spiral may not provide sufficient lateral confinement of the core to compensate for the loss of the cover. In this spiral volume context, different codes specify different amount of spiral volume as transverse (lateral) reinforcements.

Basic objective of the present work is to study the ductility behavior of circular column specimens under axial monotonic cyclic loading, confined by spirals. Different circular column specimens were studied experimentally with varying amounts of spiral volume, number of load cycles and provision of fibers.

2. PAST RESEARCH.

A brief review of the past research conducted in the following related topics is presented in this chapter. ACI 318-63 defines the columns as 'spiral reinforced columns' when the longitudinal reinforcement bars are enveloped by a continuous helix of steel bar or wire; 'tied column' when the longitudinal reinforcement bars are held in position by intermittent lateral ties.

2.1 STUDIES ON THE CONCRETE CONFINEMENT:

The principles of spiralogy date back to 1903, when Considere [20] published the results of tests conducted on columns reinforced with longitudinal bars and spirals, on the basis of which he concluded that the steel in the spiral is 2.4 times as effective in increasing the ultimate strength capacity of the column as that placed longitudinally.

Roy and Sozen [22] showed that concrete possesses ductility. They performed experimental studies using concrete cylinders with longitudinal and discrete lateral reinforcements to finally make their observations.

The response of columns subjected to cyclic loading (simulated seismic conditions) was studied by Saatcioglu and Ozcebe [5]. They observed that increase in ductility occurred with proper confinement and suggested better confinement rather than mere reduction of hoop reinforcement

spacing. Also strength degradation was found by them when the columns are subjected to bi-directional post yielding loads.

Shamim and Uzumeri [6] pointed out in their paper that closely knit cage in the longitudinal and transverse directions with well distributed lateral ties and main longitudinal steel enhances the strength and ductility of tied columns.

Ductility of spiral confined concrete columns was observed by Priestley et.al. [7], who suggested cold working of spirals for better confining action in addition to the increase in moment capacity. Overall excellent stability of hysterisis behavior under reversed cyclic loading was also observed by them.

Park et.al.[10] observed the effects of square hoops in columns and concluded that considerable increase in the ductility and enhancement in flexural strength are possible due to confinement of concrete and strain hardening of steel.

Park and Sampson [12] studied the ductility behavior of eccentrically loaded reinforced concrete column sections subjected to seismic loading conditions and suggested a method for the determination of the amount of special transverse steel required for ductility. This method is based on their experiments conducted on reinforced concrete columns provided with ties or hoops stressed upto strain

hardening range. They showed that the amount of transverse steel required for better ductility depends on the level of axial load, longitudinal steel content and strengths of steel and concrete. They observed that in order to utilize the reserve moment capacity through strain-hardening of reinforcements at large curvatures, the transverse reinforcements are to be closely spaced such that buckling of longitudinal bars is eliminated.

2.2 STUDIES ON FIBER REINFORCED CONCRETE (FRC).

So far extensive studies have been taken up by several researchers on fibrous concrete subjected to flexure but there exist a gap for FRC columns.

Swamy et.al.[8] and Craig et.al.[9] made similar observations regarding the improved ductility behavior and higher residual load carrying carrying capacity (in post failure state) in case of FRC when compared to the reinforced cement concrete.

Prestressing effects on FRC were studied by Huges [11]. He observed substantial increase in ductility and in resistance to static loading, local damage, control of cracking, impact, spalling of concrete, early thermal and shrinkage cracking and explosion or thermal shocks due to prestressing effect.

3. EXPERIMENTAL WORK.

3.0 INTRODUCTION:

The entire experimental work was divided into the following stages.

Stage 1. Selection of test specimens.

Stage 2. Reinforcement preparation.

Stage 3. Tests of the materials used in the work.

Stage 4. Preparation of specimens.

Stage 5. Experimental set-up and the actual tests.

3.1 SELECTION OF TEST SPECIMENS:

A total of seven sets of specimens were chosen and designed to study their ductility properties.

Following are the details of the specimens selected in this study.

I. CYLINDERS (Nominal dimensions: 150mm.dia x 300mm.ht)

a. Plain Cement Concrete (P.C.C.).

b. Spiral reinforced concrete.

c. Hoop reinforced concrete.

d. Plain Fibrous cement concrete (PFC.).

e. Spiral with fibrous concrete.

Cylindrical specimens were chosen to examine the influence of spiral column-reinforcements and presence of fibers in such concrete compression elements.

II. CUBES (Nominal dimensions: 150mm.x150mm.x150mm.)

a. Plain cement concrete

b. Fibrous concrete

Cubical specimens were choosen to study their ductility behavior in addition to the determination of compressive strengths of different concrete mixes used in the investigation.

1. Test specimen set ACI: These cylindrical specimens have been designed to conform with the relevant spiral requirements to ACI specifications [1], for which the governing equation is

$$Vs/Vc = 0.45\{(Ag/Ac)-1\}\ fck/fy \ldots\ldots\ldots\ldots\ldots(3.1)$$

2. Test specimen set ISS: These cylindrical specimens have been designed to conform with the relevant spiral requirements to I.S.specifications [2], for which the governing equation is

$$Vs/Vc = 0.36\{(Ag/Ac)-1\}\ fck/fy \ldots\ldots\ldots\ldots\ldots(3.2)$$

3. Test specimen set ISF: These cylindrical specimens have been designed to conform with the relevant spiral requirements to I.S.specifications [2], and made of fibrous concrete. The governing equation for the spiral volume is (3.2)

4. Test specimen set HFC: This cylindrical specimen has been designed with volume of hoop reinforcement equal to the relevant spiral requirement of I.S.specifications [2], for which the governing equation is

$$Vh/Vc = 0.36\{(Ag/Ac)-1\}\ fck/fy \ldots\ldots\ldots\ldots\ldots(3.3)$$

This specimen was choosen to compare the behavior of

hoops with spirals.

5. Test specimen set RFC: These cylindrical specimens have been designed to conform with the spiral requirements 25% less than I.S.specifications [1], for which the governing equation is

$$Vh/Vc = 0.27((Ag/Ac)-1)\ fck/fy \quad\ldots\ldots\ldots\ldots\ldots\ldots(3.4)$$

6. Test specimen set PCC: These specimens were selected to study the brittle failure of the plain concrete columns with axial load.

7. Test specimen set PFC: These specimens were chosen to compare the ductility behavior with spiraled fibrous concrete specimens.

3.2 REINFORCEMENT PREPARATION:

The typical details of the reinforcements provided in the test specimens are illustrated in table 3.1. Spiral reinforcements as shown in the figure 3.1 were made by cold working of 3mm.dia. bars. These bars were first closely wound on 90mm. outer dia. steel pipe and then released to form a spiral of 120mm. outer dia. This allowed a clear cover of 15mm. around the spiral.

To avoid local failures of the specimen at top and bottom end surfaces of the specimen in contact with the loading plates, two extra turns of spiral were provided at each end. This is in line with the I.S.Code specifications [3], which suggests one and half turns are to be provided at the end of the spiral for development length. The ACI set

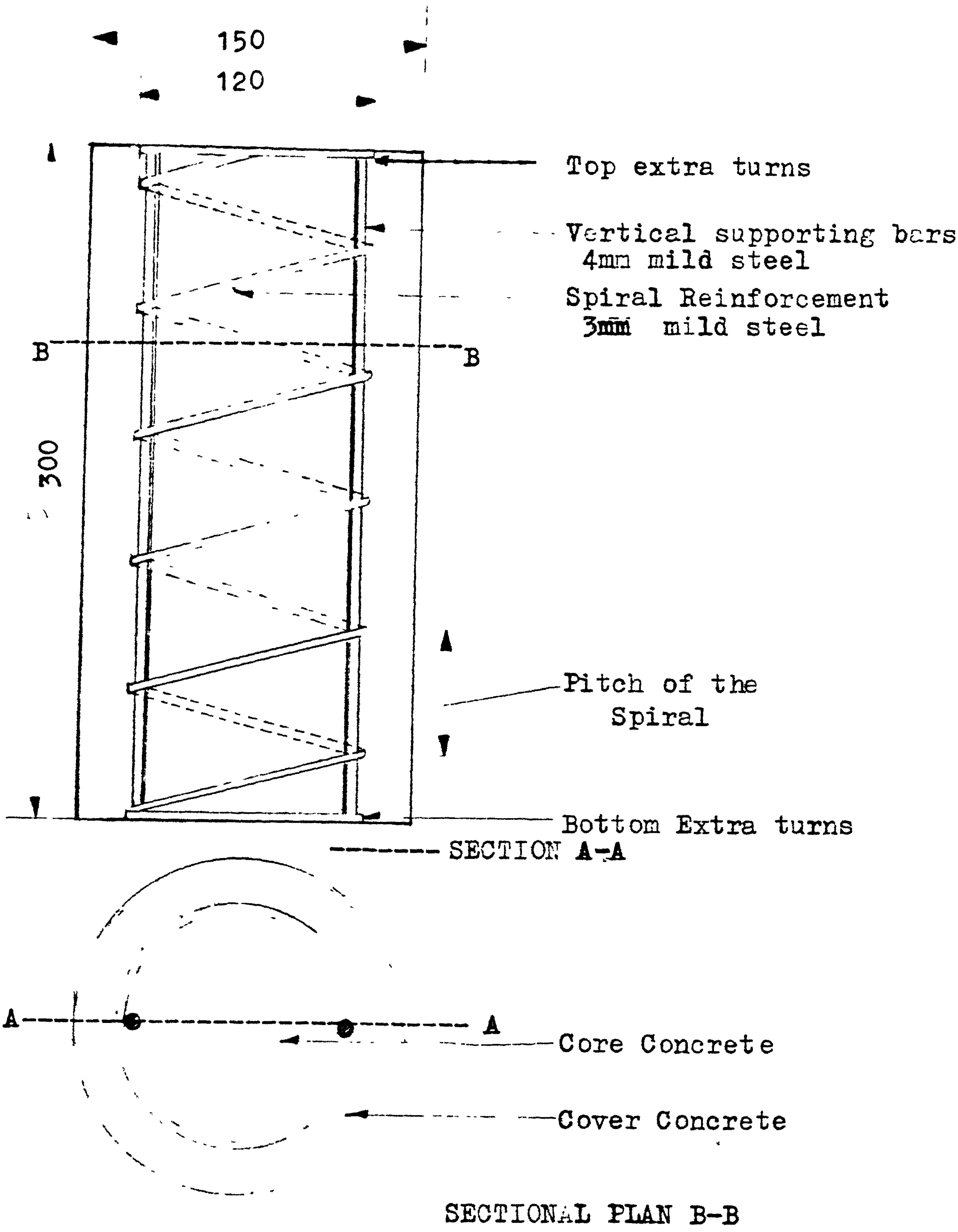


FIGURE:3.1 SPECIMENS USED IN THE STUDY
(All dimensions are in mm.)

specimens should take more load compared to the ISS set due to the increased spiral volume, hence two extra turns were adopted.

3.3 TESTS ON THE MATERIALS USED:

a) AGGREGATES (COARSE): Crushed granite stone aggregates of sizes 12mm. and down were used for the concrete mixes. This facilitated the passage of aggregates through the spirals outward into the concrete cover regions. Specific gravity of the aggregates was determined.

i) Specific gravity : 2.63

b) AGGREGATES (FINE): Ordinary river sand was used in the concrete mix, which was tested as per the requirements of the relevant IS code of practice. Results of the test are as follows.

i) Specific gravity : 2.89

c) CEMENT: To evaluate the quality of the cement to be used for the test specimens, mortar cubes were prepared and tested as per IS code. The test results are given below.

	Sample 1	Sample 2	Sample 3
i) 7 day strength (MPa)	17.86	18.6	20.3
Average 7 day strength (MPa): 18.83	S.D.: 1.115		

S.D.: Standard Deviation

d) FIBERS: For casting work using fibrous concrete, locally available mild steel wires of diameter 0.4mm. were chosen. Aspect ratio of fibers was kept at about 125 and

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TABLE 3.1: REINFORCEMENT PROVIDED IN THE SPECIMENS.

S.No	SET-	ACI	ISS	ISF	RSF	HFC*
1.	Spiral dia(mm.)	3	3	3	3	3
2.	Pitch (mm.)	19	24	24	32	25
3.	No.of turns '	19	16	16	13	14

* HFC contains circular hoops of 3mm. dia. at a spacing of 25mm c/c, includes one extra hoop each at both ends

' This no. includes two extra turns provided at the ends.

TABLE 3.2: REQUIREMENT OF MATERIAL FOR SPECIMENS.

S.No.	Mix #	SPECIMENS	CEMENT kg.	SAND kg.	COARSE AGGREGATE kg.
1.	1	ACI,ISS, Cubes	15	34	67
2.	2	PCC,Cubes	15	34	67
3.	3	ISF,RSF, HFC,PFC, CUBES	16	37	75

In Mix 3, containing specimens of the sets ISF, RSF,cubes and specimens HFC and PFC, fibers are included in the concrete. Volume fraction of fibers in this mix: 0.5%

TABLE 3.3 RESULTS OF TENSILE TEST OF FIBERS.

SNo			*Sample 1	Sample 2	Sample 3
1.	Proportional limit	N.	50.0	56.0	56.0
2.	Yield Load	N.	59.5	63.5	64.5
3.	Ultimate Load	N.	67.3	6[illegible].0	70.2
4.	Deflection at Ultimate	mm.	9.6	7.5	7.5
5.	Ductility		32.[illegible]	5.	5.[illegible]
6.	Strain at ultimate %		[illegible].5	30.0	30.0
7.	Strain rate applied /min		0.008	0.2	0.2

*. For sample 1 strain rate was 0.008 upto 40% of total elongation 0.08 from 40% to [illegible]% and 0.2 for rest of the test.

corresponding length of each fiber was about 50mm. The bundles of wires were cut to lengths of (50+/-2)mm. Based on the experiments and experience gathered from past studies [8,9,11], it was thought that this aspect ratio of 125 should provide the desired bond resistance.

Three samples of 75mm. length were randomly cut from the wire-bundle for tensile strength test. To study the effect of rate of strain on the strength, one of the samples (sample 1) was tested at very low strain rate, and two more samples were tested at moderate strain rate. Gauge length of 25mm. was kept between the upper and lower jaws of the flat plate grips of INSTRO-1195 tensile testing machine. The grip length of 25mm. was found to be adequate to develop the full strength of the fiber without an slipping. This is evident from the test plots given in figure 3.2.

e) REINFORCEMENTS: Mild steel bars of yield strength 250 MPa. are used in the specimen preparation, as illustrated in figure 3.1. to make spirals. Yield strength is used for calculating the volume of the spirals required for various specimens according to the relations (3.1) to (3.4).

3.4 PREPARATION OF SPECIMENS:

3.41 CASTING PROCEDURE and PRECASTING OPERATIONS:

Concrete cylinders and cubes were cast as per the proportions given by the relevant I.S.Codes (4)

The materials for the casting work were sieved and weighed in the required proportions. Detailed quantities are given in table 3.2

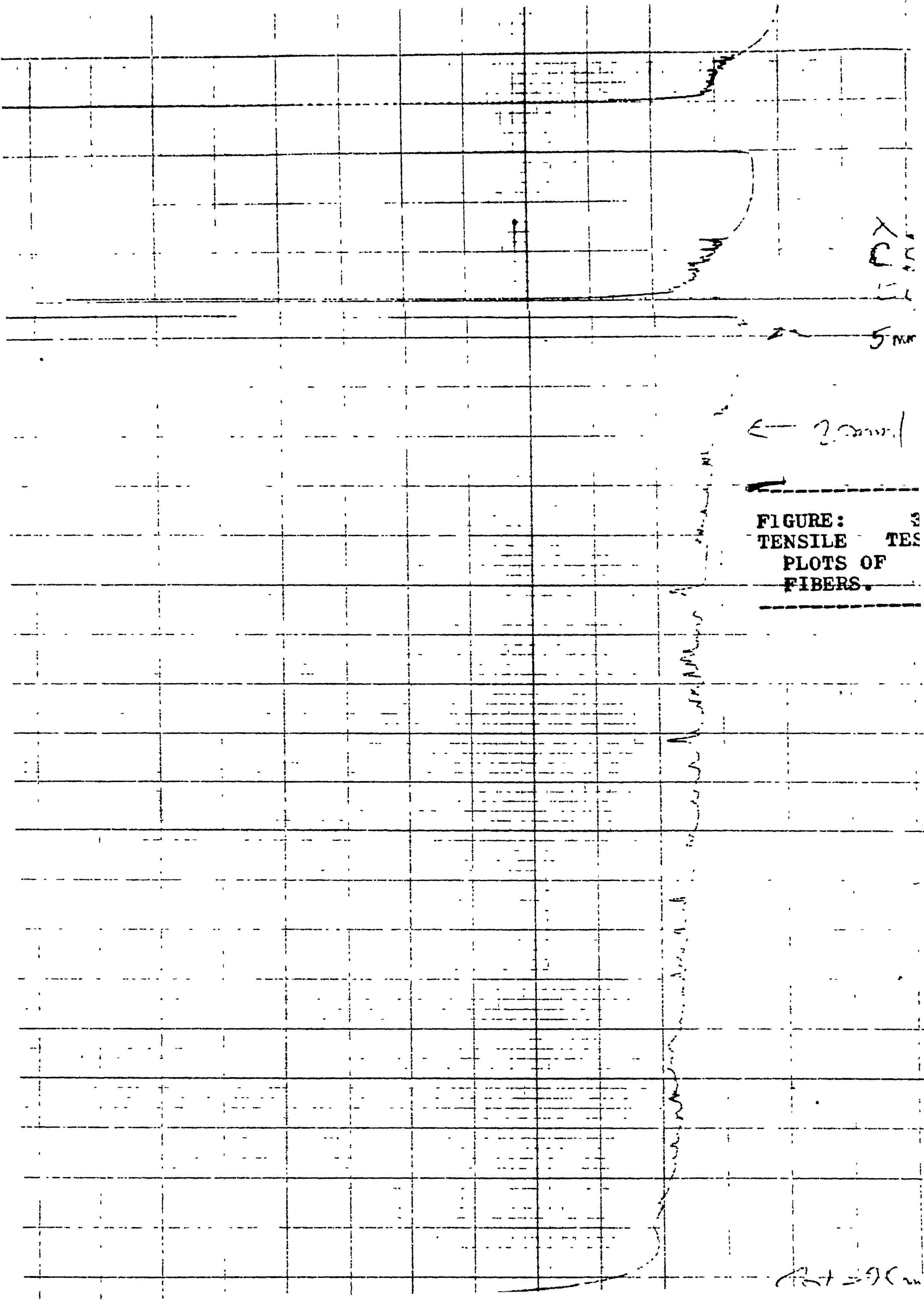

FIGURE: 3
TENSILE TES
PLOTS OF
FIBERS.

The cylindrical and cubical moulds were assembled, inner surfaces of the moulds were thoroughly cleaned and oiled. The reinforcement cages were placed inside the cylindrical moulds making sure that the bottom-most turns of the spirals are flush with the base plate of the mould.

3.42 MIXING AND PLACING OF CONCRETE:

Concrete mixing was done in a tilting type elctrically operated revolving drum mixer. Mixing time was 9 to 10 minutes for each batch. Water cement ratio was kept at 0.5 for normal concrete and 0.52 for fibrous concrete. The thoroughly mixed concrete was poured in the moulds. Standard tamping bar was used to push the concrete to remote corners of the mould. Needle vibrator was used carefully to remove the entrapped air in the concrete to produce well compacted concrete without disturbing the position of the spiral and the clear cover. Top surface was made flush with the top of the mould using 1:1 cement sand mortar applied by trowel.

3.43 POST CASTING OPERATIONS:

After 24 hours from casting, moulds were opened and the specimens were kept submerged in water tank for curing. After 28 days of curing, the specimens were removed from the curing tank, allowed to dry for one day, and then weighed. The final dimensions were also measured. These data are given in Table 5.1. The top surfaces of the cylinders were capped with plaster of paris and finished with a smooth glass plate.

3.5 EXPERIMENTAL SETUP and ACTUAL TESTING WORK:

In this study all the specimens were tested under uni-axial monotonic cyclic loading conditions for which the loads were applied through a 135 ton capacity compression testing machine. For the central 200mm. gauge length of the specimens, compressometer was fixed. Dial gauges of least count 0.01mm. were used for the axial shortening measurements. Dial gauges were also fixed between the two jaws of the loading machine to obtain the deformation of the total specimen. The test setup has been illustrated in figure 3.3.

The cylinders were tested in one or more loading cycles as the case may be. The specimen was placed over the lower jaw of the loading machine, upper jaw was brought in contact with the top surface of the specimen. A seating load of 0.25 to 0.5 tons was applied and released to assure perfect contact and reaction from the upper jaw. Load was applied, deformations were measured at regular intervals. After each cycle load was brought to minimum and the residual (permanent) set was recorded. Spalling of cover concrete, failures of vertical supporting bars and spirals were observed. The details of the loading cycles and measured deformations has been illustrated in Chapter 4.

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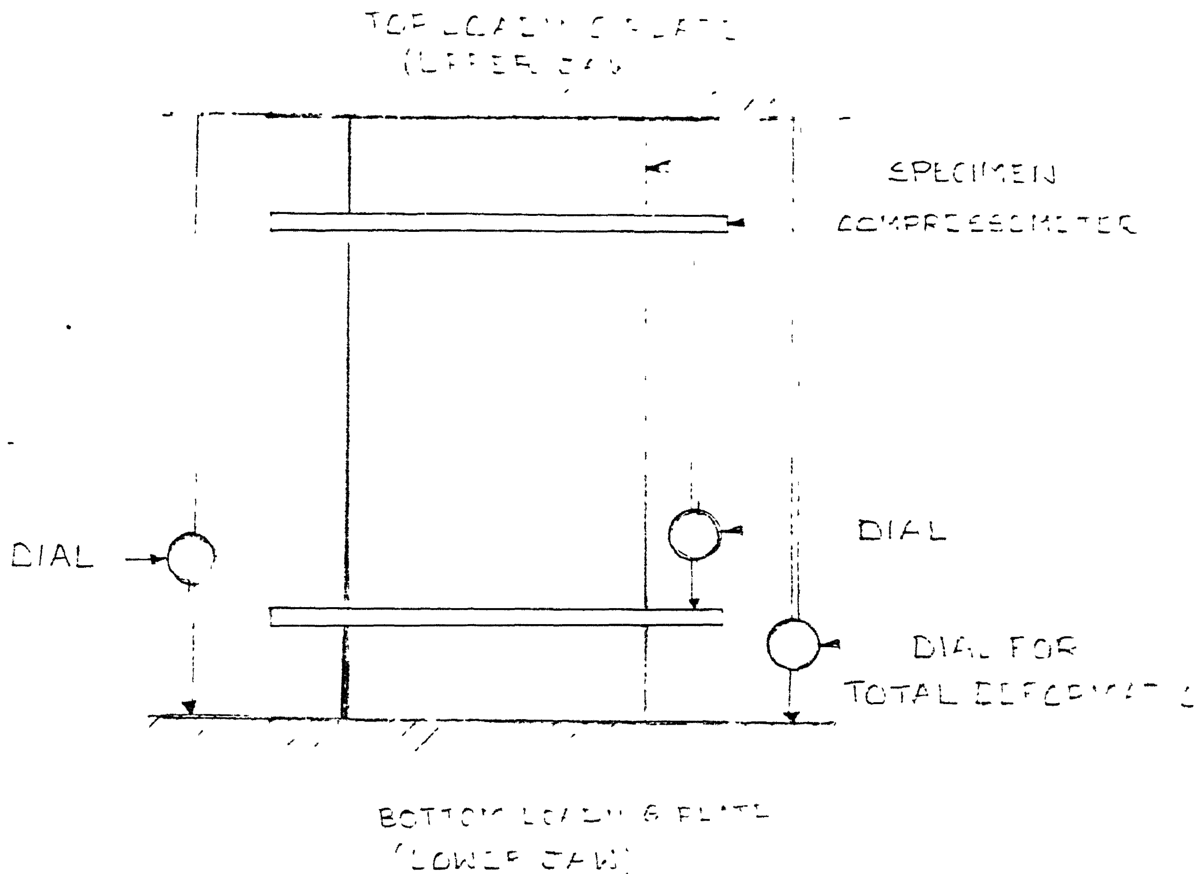


Figure: **3.3 Typical Experimental setup.**

FIG. 3.3. EXPERIMENTAL SETUP.

4. OBSERVATIONS FROM THE TESTS CONDUCTED.

From the tests conducted, following important observations were made. Maximum compressive strain of magnitude of 0.002 as recommended by the I.S.code [2] for limit state of collapse in compression has been observed for each of the specimens and corresponding load was recorded.

4.1 TEST SPECIMEN SET PCC:

This set contain specimens marked PCC1, PCC2, PCC3 and PCC4. For this test series, to measure the deformations dial-1 was set to a gauge length of central 200mm. and dial-2 to the total length of the specimen. These specimens except PCC3 were loaded to 24 tons in first cycle, after which the load was gradually released to zero and reloaded to failure. The loads and deflections were also measured in the post-failure stage upto a range of 30 to 50 percent of maximum (failure) load. Results has been illustrated in Tables 4.11 to 4.62 and Figs 4.11 to 4.62.

4.11 SPECIMEN PCC1:

-strain of magnitude 0.2% was reached at a load of 23t.

-plastic deformation started at about 28t load, strain increased from 0.00275 to 0.004 with a load step of 2t.

-sudden drop of load at 30t. was observed along with cracking sound and crushing of concrete.

-the strain at failure load was observed as 0.004in the

TABLE 4.11 RESULTS OF LOADED SPECIMEN: PCC1

	[----- READINGS	-----]		STRESS	STRAINS	
SNo	LOAD t	DIAL 1	DIAL 2	in MPa.	DIAL 1	DIAL 2
1	0.0	905.0	535.0	0.0000	0.0000	0.0000
2	2.0	905.5	545.0	1.1313	0.0000	0.0003
3	4.0	907.0	555.0	2.2626	0.0001	0.0007
4	6.0	908.5	562.0	3.3939	0.0002	0.0009
5	8.0	909.5	568.0	4.5253	0.0002	0.0011
6	10.0	912.0	573.0	5.6566	0.0004	0.0013
7	12.0	915.0	578.0	6.7879	0.0005	0.0014
8	14.0	918.0	583.0	7.9192	0.0007	0.0016
9	16.0	920.5	588.0	9.0505	0.0008	0.0018
10	18.0	924.0	592.0	10.1818	0.0010	0.0019
11	20.0	928.0	598.0	11.3131	0.0012	0.0021
12	22.0	932.0	603.0	12.4444	0.0014	0.0023
13	24.0	939.0	610.0	13.5758	0.0017	0.0025
14	0.0	915.5	577.5	0.0000	0.0005	0.0014
15	5.0	919.0	599.0	2.8283	0.0007	0.0021
16	10.0	926.0	608.0	5.6566	0.0011	0.0024
17	15.0	933.0	615.0	8.4848	0.0014	0.0027
18	20.0	940.0	622.0	11.3131	0.0018	0.0029
19	22.0	943.0	627.0	12.4444	0.0019	0.0031
20	24.0	947.0	632.0	13.5758	0.0021	0.0032
21	26.0	952.0	640.0	14.7071	0.0024	0.0035
22	28.0	960.0	648.0	15.8384	0.0028	0.0038
23	30.0	985.0	671.0	16.9697	0.0040	0.0045
24	16.0	1207.0	870.0	9.0505	0.0151	0.0112
25	14.0	1226.0	895.0	7.9192	0.0161	0.0120
26	13.0	1237.0	915.0	7.3535	0.0166	0.0127
27	12.0	1254.0	931.0	6.7879	0.0175	0.0132
28	11.0	1275.0	955.0	6.2222	0.0185	0.0140
29	10.0	1302.0	982.0	5.6566	0.0199	0.0149

central part and 0.0045 in the total length of the specimen.

-in the post failure stage, the specimen was tested upto a maximum strain of 0.01985.

4.12 SPECIMEN PCC2:

-strain of magnitude 0.002 was reached at a load of 20t.

-plastic deformation started at about 28t load, strain increased from 0.0029 to 0.0037 with a load step of 2t.

-sudden drop of load at 31t. was observed along with cracking sound and crushing of concrete.

-the strain at failure load was observed as 0.0086 in the central part and 0.0083 in the total length of the specimen.

-in the post failure stage, the specimen was tested upto a maximum strain of 0.022.

4.13 SPECIMEN PCC3:

-strain of magnitude 0.002 was reached at a load of 13t.

-sudden drop of load at 24t. was observed along with cracking sound and crushing of concrete.

-the strain at failure load was observed as 0.0042 in the central part and 0.0045 in the total length of the specimen.

4.14 SPECIMEN PCC4:

-strain of magnitude 0.002 was reached at a load of 28t.

-plastic deformation started at about 28t load, strain increased from 0.0026 to 0.00335 with a load step of 2t.

-sudden drop of load at 32t. was observed along with cracking sound and crushing of concrete.

-the strain at failure load was observed as 0.00335 in the

TABLE 4.12 RESULTS OF LOADED SPECIMEN: PCC2

	[----- READINGS	-----]		STRESS	%STRAINS	
SNo	LOAD t	DIAL 1	DIAL 2	in MPa.	DIAL 1	DIAL 2
1	0.0	528.0	400.0	0.0000	0.0000	0.0000
2	2.0	529.0	411.0	1.1313	0.0050	0.0367
3	4.0	531.5	426.0	2.2626	0.0175	0.0867
4	6.0	534.0	440.0	3.3939	0.0300	0.1333
5	8.0	536.0	450.0	4.5253	0.0400	0.1667
6	10.0	538.5	457.0	5.6566	0.0525	0.1900
7	12.0	542.0	464.0	6.7879	0.0700	0.2133
8	14.0	545.0	470.0	7.9192	0.0850	0.2333
9	16.0	549.0	476.0	9.0505	0.1050	0.2533
10	18.0	554.0	481.0	10.1818	0.1300	0.2700
11	20.0	560.0	487.0	11.3131	0.1600	0.2900
12	22.0	566.0	492.0	12.4444	0.1900	0.3067
13	24.0	574.0	498.0	13.5758	0.2300	0.3267
14	0.0	542.0	480.0	0.0000	0.0700	0.2667
15	5.0	547.5	510.0	2.8283	0.0975	0.3667
16	10.0	556.0	515.0	5.6566	0.1400	0.3833
17	15.0	562.5	521.0	8.4848	0.1725	0.4033
18	20.0	569.0	529.0	11.3131	0.2050	0.4300
19	22.0	574.0	534.0	12.4444	0.2300	0.4467
20	24.0	578.0	540.0	13.5758	0.2500	0.4667
21	26.0	582.0	546.0	14.7071	0.2700	0.4867
22	28.0	586.0	556.0	15.8384	0.2900	0.5200
23	28.0	588.0	560.0	15.8384	0.3000	0.5333
24	28.0	590.0	564.0	15.8384	0:3100	0.5467
25	30.0	603.0	569.0	16.9697	0.3750	0.5633
26	31.0	700.0	650.0	17.5354	0.8600	0.8333
27	21.0	785.0	717.0	11.8788	1.2850	1.0567
28	20.0	808.0	735.0	11.3131	1.4000	1.1167
29	18.0	838.0	755.0	10.1818	1.5500	1.1833
30	16.0	865.0	776.0	9.0505	1.6850	1.2533
31	14.0	897.0	800.0	7.9192	1.8450	1.3333
32	12.0	928.0	823.0	6.7879	2.0000	1.4100
33	10.0	968.0	850.0	5.6566	2.2000	1.5000

Figure: 4.11 Plot of Stress-Strain for specimen - PCC1.

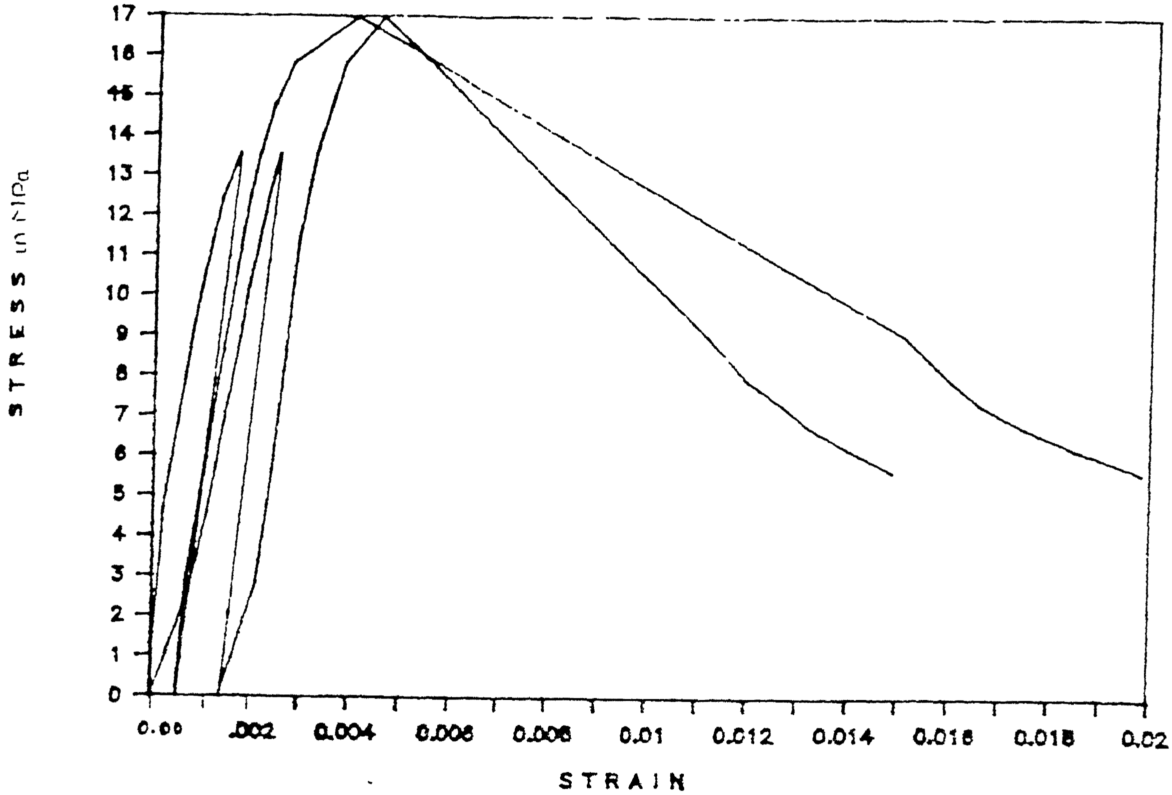


Figure: 4.12 Plot of Stress-Strain for specimen - PCC2.

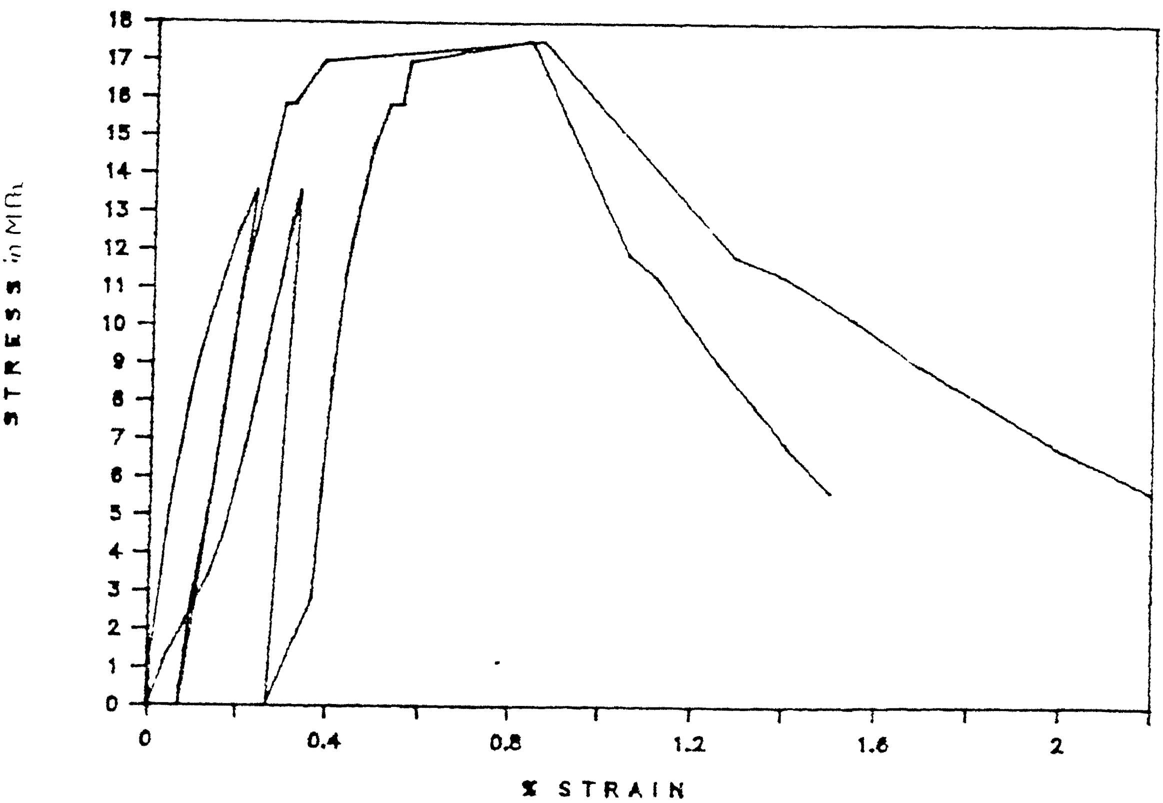


TABLE 4.13 RESULTS OF LOADED SPECIMEN: PCC4

	[-----	READINGS	-----]	STRESS	%STRAINS	
SNo	LOAD t	DIAL 1	DIAL 2	in MPa.	DIAL 1	DIAL 2
1	0.0	15.0	7.5	0.0000	0.0000	0.0000
2	2.0	15.0	7.6	1.1313	0.0050	0.0267
3	4.0	15.0	7.7	2.2626	0.0100	0.0500
4	6.0	15.0	7.7	3.3939	0.0175	0.0700
5	8.0	15.0	7.8	4.5253	0.0225	0.0833
6	10.0	15.1	7.8	5.6566	0.0350	0.0933
7	12.0	15.1	7.8	6.7879	0.0450	0.1067
8	14.0	15.1	7.9	7.9192	0.0550	0.1200
9	16.0	15.1	7.9	9.0505	0.0700	0.1333
10	18.0	15.1	7.9	10.1818	0.0800	0.1467
11	20.0	15.2	8.0	11.3131	0.0950	0.1633
12	22.0	15.2	8.0	12.4444	0.1100	0.1767
13	24.0	15.3	8.1	13.5758	0.1350	0.1967
14	0.0	15.0	7.9	0.0000	0.0175	0.1167
16	5.0	15.1	7.9	2.8283	0.0450	0.1467
17	10.0	15.1	8.0	5.6566	0.0675	0.1767
18	15.0	15.2	8.1	8.4848	0.0950	0.2000
19	20.0	15.2	8.2	11.3131	0.1200	0.2267
20	25.0	15.3	8.3	14.1414	0.1550	0.2567
21	27.0	15.3	8.4	15.2727	0.1800	0.2833
22	29.0	15.4	8.5	16.4040	0.2200	0.3167
23	30.0	15.5	8.5	16.9697	0.2600	0.3400
24	30.0	15.6	8.6	16.9697	0.2950	0.3733
25	32.0	15.7	8.7	18.1010	0.3350	0.4100
26	27.0	16.5	9.8	15.2727	0.7600	0.7500
27	25.0	16.7	10.0	14.1414	0.8700	0.8300
28	21.0	17.1	10.3	11.8788	0.9400	0.9400
29	20.0	17.2	10.5	11.3131	1.1150	0.9833

central part and 0.0041 in the total length of the specimen.

-in the post failure stage, the specimen was tested upto a maximum strain of 0.01115, the specimen was unable to maintain the load after a load of 20t.

4.2 TEST SPECIMEN SET ACI:

The specimens in this series were marked as ACI1, ACI3 and ACI6. In this set dial-1 was set for the central 200mm. gauge length, dial-2 and dial-3 were set for the total length of the specimen. In ACI1, vertical bars supporting the spiral were placed outside the spiral. In all the specimens failure was initiated by the failure of spiral in tension and then crushing of concrete in the un-confined region. Then the specimens were unloaded.

4.21 SPECIMEN ACI1:

-strain of magnitude 0.002 was reached at a load of 26t.

-plastic deformation started at about 35t load, strain increased from 0.0047 to 0.00705 with a load step of 5t.

-sudden drop of load at 40t. was observed along with cracking sound of concrete.

-one of the verticals buckled at a load of 46t where as the other buckled at a load of 50t.

-the strain at failure load of 52t was observed as 0.0403 in the central part of the specimen.

4.22 SPECIMEN ACI3:

-strain of magnitude 0.002 was reached at a load of 25t.

-plastic deformation started at about 30t load, strain

TABLE 4.21 RESULTS OF LOADED SPECIMEN: ACI1

		--------READINGS--------			STRESS	--- %	STRAINS------	
SNo	LOADt	DIAL1	DIAL2	DIAL3	in MPa	DIAL1	DIAL 2	DIAL 3
1	0	999	235	660	0.0000	0.0000	0.0000	0.0000
2	2	1000	242	670	1.1310	0.0050	0.0233	0.0333
3	4	1002	248	678	2.2630	0.0150	0.0433	0.0600
4	6	1003.5	257	687	3.3940	0.0225	0.0733	0.0900
5	8	1005	265	695.5	4.5250	0.0300	0.1000	0.1183
6	10	1007	272	702	5.6570	0.0400	0.1233	0.1400
7	0	1000.5	264	668	0.0000	0.0075	0.0967	0.0267
8	5	1003	275	705.5	2.8280	0.0200	0.1333	0.1517
9	10	1007	287	718	5.6570	0.0400	0.1733	0.1933
10	15	1012	301	732.5	8.4850	0.0650	0.2200	0.2417
11	20	1019	313	746	11.3130	0.1000	0.2600	0.2867
12	25	1030	327.5	763	14.1410	0.1550	0.3083	0.3433
13	0	1008	310	720	0.0000	0.0450	0.2500	0.2000
14	5	1013	395	734	2.8280	0.0700	0.5333	0.2467
15	10	1019	405.5	745	5.6570	0.1000	0.5683	0.2833
16	15	1024	412	752	8.4850	0.1250	0.5900	0.3067
17	20	1029	418	759	11.3130	0.1500	0.6100	0.3300
18	25	1036	425	767	14.1410	0.1850	0.6333	0.3567
19	30	1052	440	782.5	16.9700	0.2650	0.6833	0.4083
20	35	1081	468	813	19.7980	0.4100	0.7767	0.5100
21	35	1093	477	822	19.7980	0.4700	0.8067	0.5400
22	40	1140	518	867	22.6260	0.7050	0.9433	0.6900
23	42	1192	552	904	23.7580	0.9650	1.0567	0.8133
24	44	1242	592	942	24.8890	1.2150	1.1900	0.9400
25	45	1295	630	980	25.4550	1.4800	1.3167	1.0667
26	46	995			26.0200	1.6300	1.3667	1.1167
27	48	1070			27.1520	2.0050	1.5500	1.3667
28	50	1275			28.2830	2.9800	2.2833	2.0500
29	52	1450			29.4140	4.0300	2.8833	2.6333

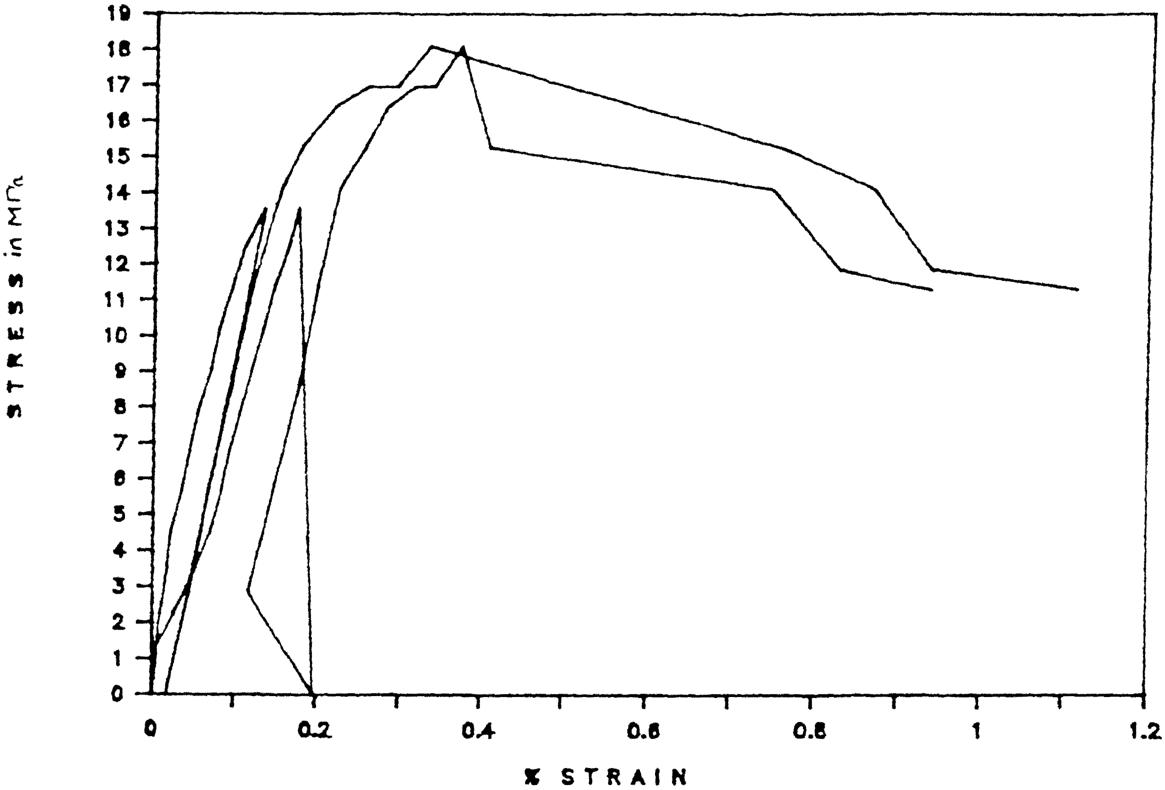


Fig re: ..13 Plot of Str -strain forspecimen POC4.

Figure : 4.21 Plot of Stress-Strain for specimen - ACI1.

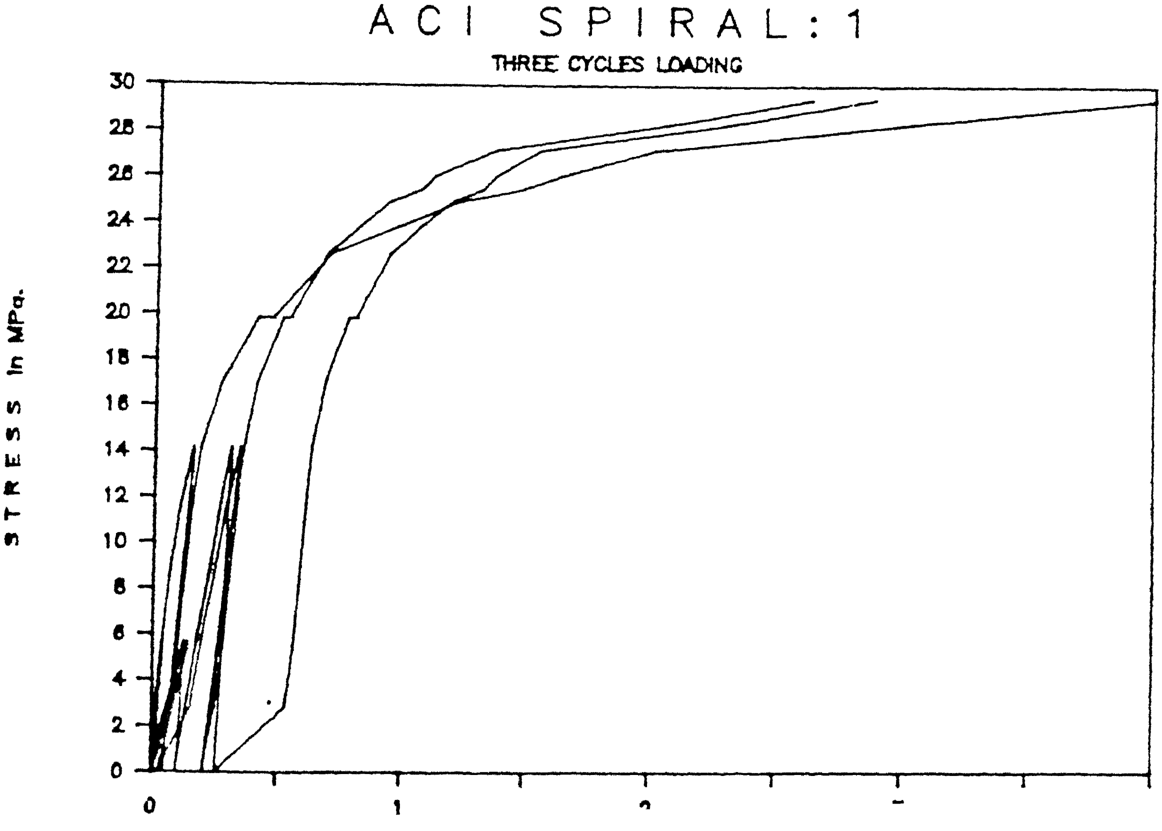


TABLE 4.22 RESULTS OF LOADED SPECIMEN: ACI3

	--------READINGS--------				STRESS	--- %	STRAINS------	
SNo	LOADt	DIAL1	DIAL2	DIAL3	in MPa	DIAL1	DIAL 2	DIAL 3
1	0.0	913.0	424.0	78.0	0.0000	0	0	0
2	2.0	914.0	460.0	145.0	1.1313	0.005	0.12	0.2233
3	4.0	916.0	480.0	163.0	2.2626	0.015	0.1866	0.2833
4	6.0	917.0	500.0	179.0	3.3939	0.02	0.2533	0.3366
5	8.0	919.0	514.0	192.0	4.5253	0.03	0.3	0.38
6	10.0	921.0	528.0	204.0	5.6566	0.04	0.3466	0.42
7	12.0	923.5	539.0	217.0	6.7879	0.0525	0.3833	0.4633
8	14.0	926.5	552.0	224.0	7.9192	0.0675	0.4266	0.4866
9	16.0	930.0	563.0	233.0	9.0505	0.085	0.4633	0.5166
10	18.0	933.5	573.0	242.0	10.1818	0.1025	0.4966	0.5466
11	20.0	937.5	583.0	250.0	11.3131	0.1225	0.53	0.5733
12	22.0	946.5	599.0	263.0	12.4444	0.1675	0.5833	0.6166
13	24.0	950.0	605.0	269.0	13.5758	0.185	0.6033	0.6366
14	0.0	925.0	525.0	176.0	0.0000	0.06	0.3366	0.3266
15	5.0	930.0	573.0	260.0	2.8283	0.085	0.4966	0.6066
16	10.0	936.5	588.0	272.0	5.6566	0.1175	0.5466	0.6466
17	15.0	942.0	599.0	280.0	8.4848	0.145	0.5833	0.6733
18	20.0	948.0	611.0	289.0	11.3131	0.175	0.6233	0.7033
19	25.0	955.0	627.0	304.0	14.1414	0.21	0.6766	0.7533
20	30.0	970.0	646.0	325.0	16.9697	0.285	0.74	0.8233
21	35.0	1002.0	678.0	358.0	19.7980	0.445	0.8466	0.9333
22	37.0	1032.0	701.0	378.0	20.9293	0.595	0.9233	1
23	39.0	1058.0	719.0	396.0	22.0606	0.725	0.9833	1.06
24	41.0	1085.0	740.0	420.0	23.1919	0.86	1.0533	1.14
25	43.0	1130.0	782.0	455.0	24.3232	1.085	1.1933	1.2566
26	45.0	1190.0	832.0	505.0	25.4545	1.385	1.36	1.4233
27	47.0	1260.0	895.0	560.0	26.5859	1.735	1.57	1.6066
28	49.0	1320.0	925.0	590.0	27.7172	2.035	1.67	1.7066
29	51.0	1390.0	965.0	630.0	28.8485	2.385	1.8033	1.84

TABLE 4.23 RESULTS OF LOADED SPECIMEN: ACI6

SNo	LOAD	DIAL1	DIAL 2	DIAL 3	STRESS	DIAL1	DIAL2	DIAL3
1	0.0	36.5	21.0	12.0	0.0000	0.0000	0.0000	0.0000
2	2.0	37.5	22.5	14.0	1.1313	0.0050	0.0050	0.0067
3	4.0	38.0	25.0	16.0	2.2626	0.0075	0.0133	0.0133
4	6.0	40.0	37.0	29.0	3.3939	0.0175	0.0533	0.0567
5	8.0	42.0	47.0	38.0	4.5253	0.0275	0.0867	0.0867
6	10.0	44.0	57.0	49.0	5.6566	0.0375	0.1200	0.1233
7	12.0	46.0	64.0	55.0	6.7879	0.0475	0.1433	0.1433
8	14.0	48.0	69.0	60.0	7.9192	0.0575	0.1600	0.1600
9	16.0	49.5	73.0	66.0	9.0505	0.0650	0.1733	0.1800
10	18.0	54.0	81.5	73.0	10.1818	0.0875	0.2017	0.2033
11	20.0	55.0	86.0	77.0	11.3131	0.0925	0.2167	0.2167
12	22.0	58.0	90.0	82.0	12.4444	0.1075	0.2300	0.2333
13	24.0	62.0	97.0	89.0	13.5758	0.1275	0.2533	0.2567
14	26.0	68.0	106.0	98.0	14.7071	0.1575	0.2833	0.2867
15	28.0	71.0	111.0	104.0	15.8384	0.1725	0.3000	0.3067
16	30.0	77.0	118.0	111.0	16.9697	0.2025	0.3233	0.3300
17	32.0	84.0	127.0	118.0	18.1010	0.2375	0.3533	0.3533
18	34.0	96.0	141.0	131.0	19.2323	0.2975	0.4000	0.3967
19	36.0	110.0	151.0	142.0	20.3636	0.3675	0.4333	0.4333
20	38.0	130.0	169.0	159.0	21.4949	0.4675	0.4933	0.4900
21	40.0	155.0	188.0	182.0	22.6263	0.5925	0.5567	0.5667
22	42.0	195.0	218.0	210.0	23.7576	0.7925	0.6567	0.6600
23	44.0	245.0	248.0	240.0	24.8889	1.0425	0.7567	0.7600
24	46.0	305.0	293.0	285.0	26.0202	1.3425	0.9067	0.9100
25	48.0	400.0	406.0	335.0	27.1515	1.8175	1.2833	1.0767
26	55.0	550.0	523.0	450.0	31.1111	2.5675	1.6733	1.4600

Figure : 4.22 Plot of Stress-Strain for specimen - ACI3.

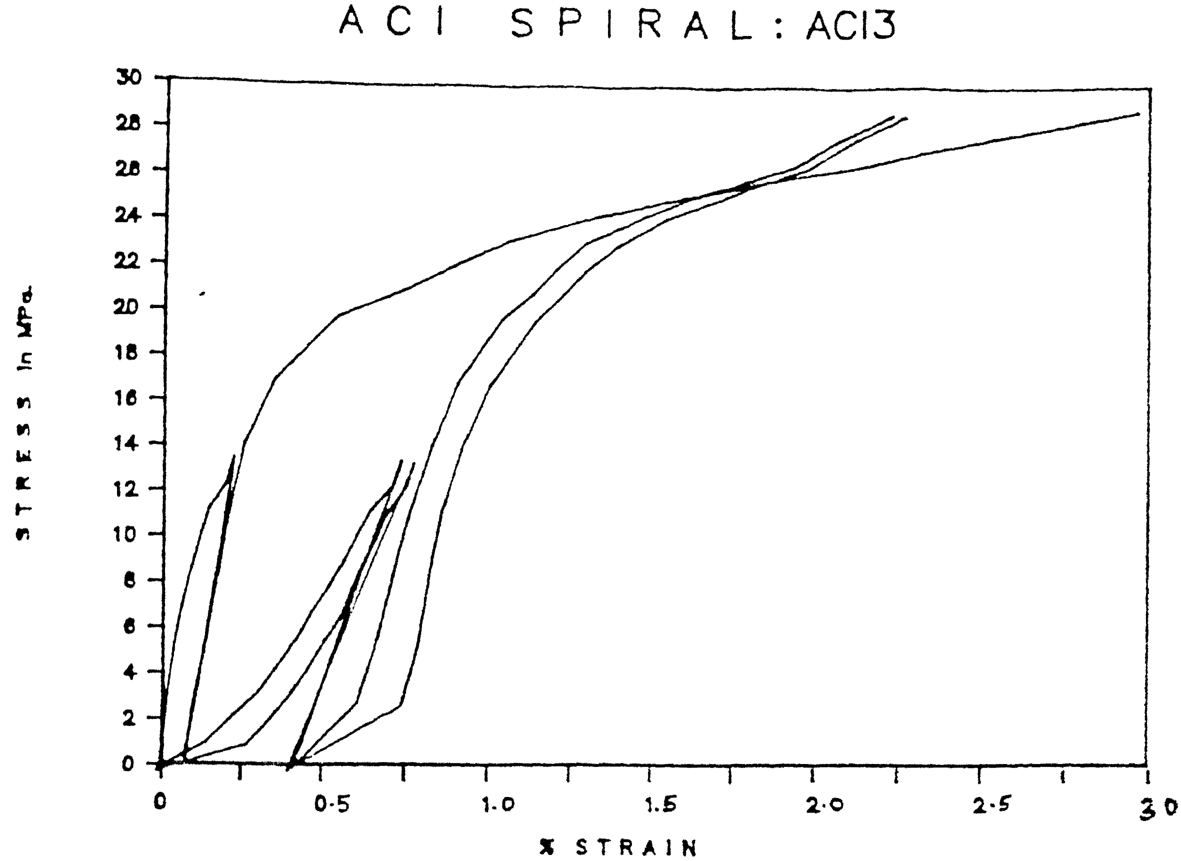
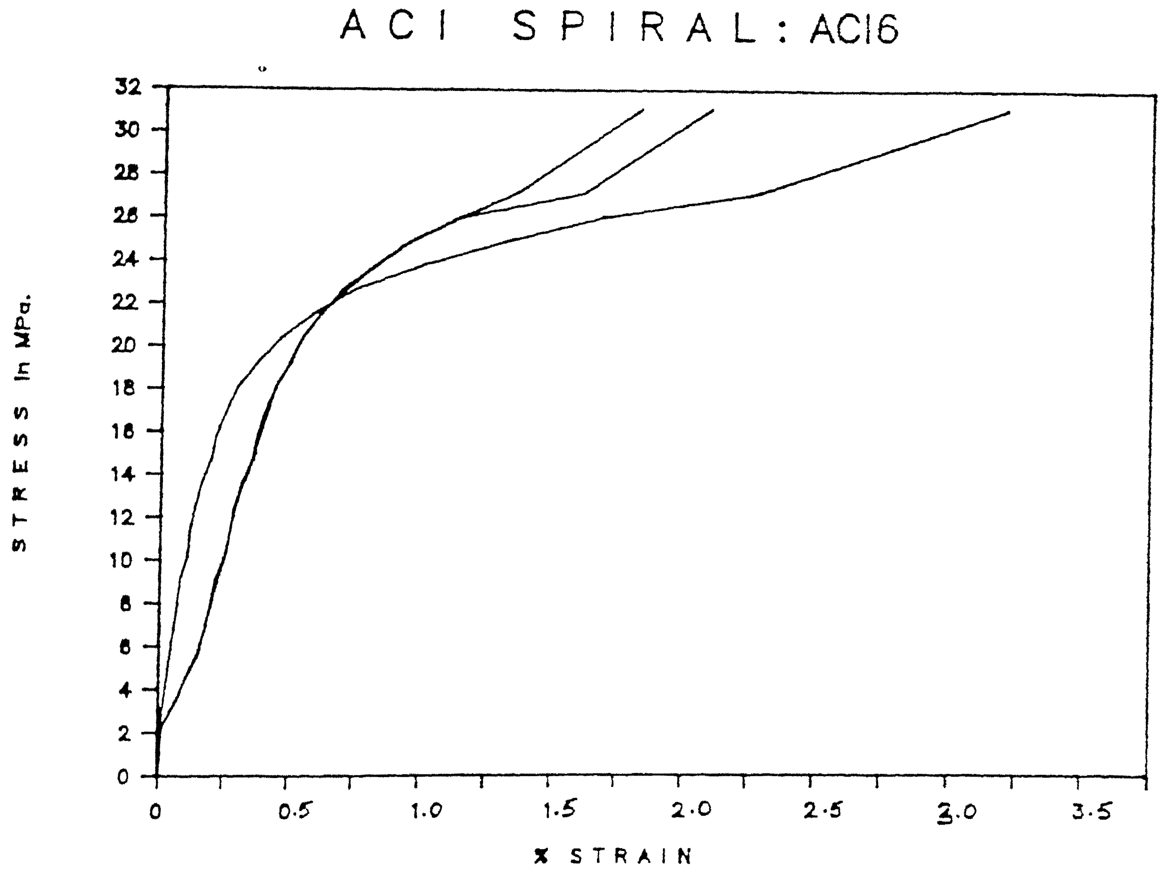


Figure: 4.23 Plot of Stress-Strain for specimen - ACI6.



increased from 0.00285 to 0.00445 with a load step of 5t.

-sudden drop of load at 39t. was observed along with cracking

-the strain at failure load was observed as 0.04435 in the central part of the specimen.

4.23 SPECIMEN ACI6:

-during the load application, load carrying capacity decreased

-when the spiral came into action, load capacity increased

-strain of magnitude 0.002 was reached at a load of 30t.

-plastic deformation started at about 40t load, strain increased from 0.005925 to 0.007925 with a load step of 2t.

-sudden drop of load at 38t. was observed along with cracking sound and crushing of concrete.

-the strain at failure load was observed as .025675 in the central part of the specimen.

4.3 TEST SPECIMEN SET ISS:

In this test series specimens were marked as ISS1, ISS2 and ISS3. For ISS1 and ISS3 dial-1 was set for the central 220mm. gauge-length and dial-2 was set for the total length of the specimen. For ISS2, both dials were set for the central 220mm. gauge-length.

4.31 SPECIMEN ISS1:

-for this specimen load was applied in the elastic range for the first two cycles. This was verified by the test results (table 4.31 & fig 4.31)

TABLE 4.31 RESULTS OF LOADED SPECIMEN: ISS1

	[---READINGS-----]			STRESS	[% STRAINS]		REMARKS.
SNo	LOAD	DIAL1	DIAL2	in MPa	DIAL1	DIAL2	
1	0.0	747.0	728.5	0.00	0.00	0.00	CYCLE 1
2	2.0	747.5	735.0	1.13	0.00	0.02	
3	4.0	749.0	743.5	2.26	0.01	0.05	
4	6.0	750.5	752.0	3.39	0.02	0.08	
5	8.0	753.0	758.5	4.53	0.03	0.10	
6	10.0	755.0	766.0	5.66	0.04	0.13	
7	1.0	750.0	745.0	0.57	0.01	0.06	CYCLE 2
8	2.0	751.0	750.0	1.13	0.02	0.07	
9	4.0	752.0	755.5	2.26	0.02	0.09	
10	6.0	753.5	759.5	3.39	0.03	0.10	
11	8.0	777.5	764.0	4.53	0.14	0.12	
12	10.0	755.5	767.0	5.66	0.04	0.13	
13	1.0	750.0	746.5	0.57	0.01	0.06	CYCLE 3
14	5.0	752.5	759.0	2.83	0.03	0.10	
15	10.0	756.0	768.5	5.66	0.04	0.13	
16	15.0	761.5	784.0	8.48	0.07	0.19	
17	20.0	768.0	801.5	11.31	0.10	0.24	
18	0.0	753.0	760.0	0.00	0.03	0.11	CYCLE 4
19	5.0	761.0	772.5	2.83	0.06	0.15	
20	10.0	765.0	784.5	5.66	0.08	0.19	
21	15.0	769.0	793.5	8.48	0.10	0.22	
22	20.0	772.5	802.0	11.31	0.12	0.25	
23	25.0	776.0	812.0	14.14	0.13	0.28	
24	1.0	760.5	770.0	0.57	0.06	0.14	CYCLE 5
25	5.0	765.0	783.5	2.83	0.08	0.18	
26	10.0	769.0	795.5	5.66	0.10	0.22	
27	15.0	772.0	803.0	8.48	0.11	0.25	
28	20.0	774.5	809.0	11.31	0.13	0.27	
29	25.0	775.0	817.0	14.14	0.13	0.30	
30	30.0	784.0	830.0	16.97	0.17	0.34	
31	35.0	797.0	851.0	19.80	0.23	0.41	
32	40.0	830.0	890.0	22.63	0.38	0.54	CRACKING
33	42.0	870.0	929.0	23.76	0.56	0.67	
34	44.0	958.0	1020.0	24.89	0.96	0.97	
35	46.0	1010.0	1070.0	26.02	1.20	1.14	
36	48.0	1100.0	1145.0	27.15	1.60	1.39	
37	50.0	1170.0	1240.0	28.28	1.92	1.71	Max. LOAD
38	50.0	1250.0	1320.0	28.28	2.29	1.97	
39	50.0	1310.0	1370.0	28.28	2.56	2.14	
40	50.0	1345.0	1400.0	28.28	2.72	2.24	
41	50.0	1380.0	1430.0	28.28	2.88	2.34	SPIRAL FAILED
42	43.0	1440.0	1490.0	24.32	3.15	2.54	
43	42.0	1500.0	1568.0	23.76	3.42	2.80	SPIRAL FAILED
44	33.0	1570.0	1625.0	18.67	3.74	2.99	
45	31.0	1640.0	1700.0	17.54	4.06	3.24	
46	22.0	1740.0	1800.0	12.44	4.51	3.57	
47	18.0	1840.0	1900.0	10.18	4.97	3.91	

-strain of magnitude 0.002 was reached at a load of 33t.

-sudden drop of load at 42t. was observed along with cracking

-plastic deformation started at about 48t load, strain increased from 0.016045 to 0.028772 with a load step of 2t.

-the strain at failure load was observed as 0.028773 in the central part and 0.0234 in the total length of the specimen.

-spiral failed at the center of the specimen due to the bulging of concrete.

-sudden drop of the load from 50t to 43t and 42t to 33t was observed when the spirals failed in succession.

-in the post failure stage, the specimen was tested unto a maximum strain of 0.497 and then unloaded.

4.32 SPECIMEN ISS2:

-for this specimen first load cycle was in elastic range. This was further verified by the test results (table 4.32 & fig 4.32)

-strain of magnitude 0.002 was reached at a load of 31t.

-drop of load at 39t. was observed with cracking of concrete

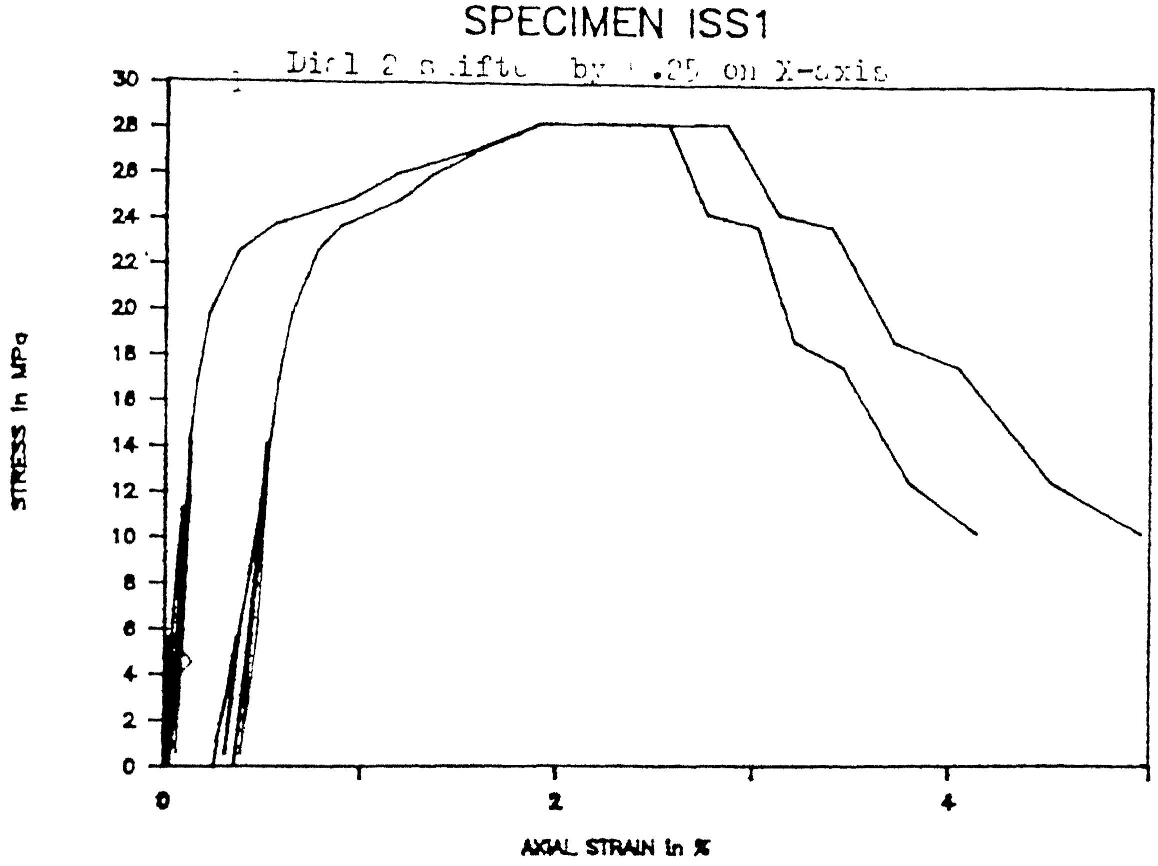
-cover failed completely and fell apart, plastic deformation started at about 40t load and strain increased from 0.0090 to 0.016 with a load step of 2t.

-the strain at failure load of 43.25t. was observed as 0.0204 in the central part and 0.0203 in the total length of the specimen

Table 4.32, RESULTS OF LOADED SPECIMEN: ISS2

SNo	[READINGS LOAD	DIAL1	DIAL2]	STRESS in MPa	[%STRAINS DIAL1	DIAL2]	
1	0.0	1357.0	540.0	0.00	0.00	0.00	CYCLE 1
2	2.0	1358.0	541.0	1.13	0.00	0.00	
3	4.0	1359.0	542.0	2.26	0.01	0.01	
4	6.0	1361.5	543.0	3.39	0.02	0.01	
5	8.0	1364.0	544.0	4.53	0.03	0.02	
6	10.0	1366.5	545.0	5.66	0.04	0.02	
7	0.0	1358.0	546.0	0.00	0.00	0.03	(dials reset)
8	0.0	1342.0	554.5	0.00	0.00	0.03	CYCLE 2
9	2.0	1343.0	555.0	1.13	0.01	0.03	
10	4.0	1343.5	555.5	2.26	0.01	0.03	
11	6.0	1344.0	556.0	3.39	0.01	0.03	
12	8.0	1344.5	556.5	4.53	0.02	0.04	
13	10.0	1345.5	557.0	5.66	0.02	0.04	
14	12.0	1347.5	557.5	6.79	0.03	0.04	
15	14.0	1350.0	558.0	7.92	0.04	0.04	
16	16.0	1352.0	559.0	9.05	0.05	0.05	
17	18.0	1354.5	561.5	10.18	0.06	0.06	
18	20.0	1356.5	564.0	11.31	0.07	0.07	
19	0.0	1344.5	555.0	0.00	0.02	0.03	(dial 1 reset)
20	0.0	1340.5	555.0	0.00	0.02	0.03	CYCLE 3
21	2.0	1341.0	556.0	1.13	0.02	0.03	
22	4.0	1341.5	557.0	2.26	0.02	0.04	
23	6.0	1342.0	559.0	3.39	0.02	0.05	
24	8.0	1342.5	561.5	4.53	0.02	0.06	
25	10.0	1343.0	563.0	5.66	0.03	0.07	
26	12.0	1344.5	565.0	6.79	0.03	0.08	
27	14.0	1346.0	566.5	7.92	0.04	0.08	
28	16.0	1347.0	568.0	9.05	0.05	0.09	
29	18.0	1349.0	569.0	10.18	0.05	0.09	
30	20.0	1351.0	570.0	11.31	0.06	0.10	
31	22.0	1353.0	572.0	12.44	0.07	0.11	
32	24.0	1356.0	574.0	13.58	0.09	0.12	
33	26.0	1359.0	576.0	14.71	0.10	0.13	
34	28.0	1362.5	579.5	15.84	0.12	0.14	
35	30.0	1368.0	589.0	16.97	0.14	0.18	
36	32.0	1379.0	598.0	18.10	0.19	0.23	
37	34.0	1394.0	610.0	19.23	0.26	0.28	
38	36.0	1420.0	632.0	20.36	0.38	0.38	CRACKING STARTED
39	36.0	1452.0	656.0	20.36	0.52	0.49	
40	38.0	1460.0	664.0	21.49	0.56	0.53	
41	39.0	1490.0	705.0	22.06	0.70	0.71	
42	40.0	1525.0	747.0	22.63	0.85	0.90	
43	42.0	1585.0	810.0	23.76	1.13	1.19	
44	42.0	1648.0	887.0	23.76	1.41	1.54	
45	42.0	1685.0	895.0	23.76	1.58	1.58	
46	43.3	1785.0	996.0	24.46	2.04	2.03	Max.LOAD, SPIRAL
47	0.0	1673.0	945.0	0.00	1.53	1.80	FAILED

Figure:4.31 Plot of Stress-Strain for specimen - ISS1.



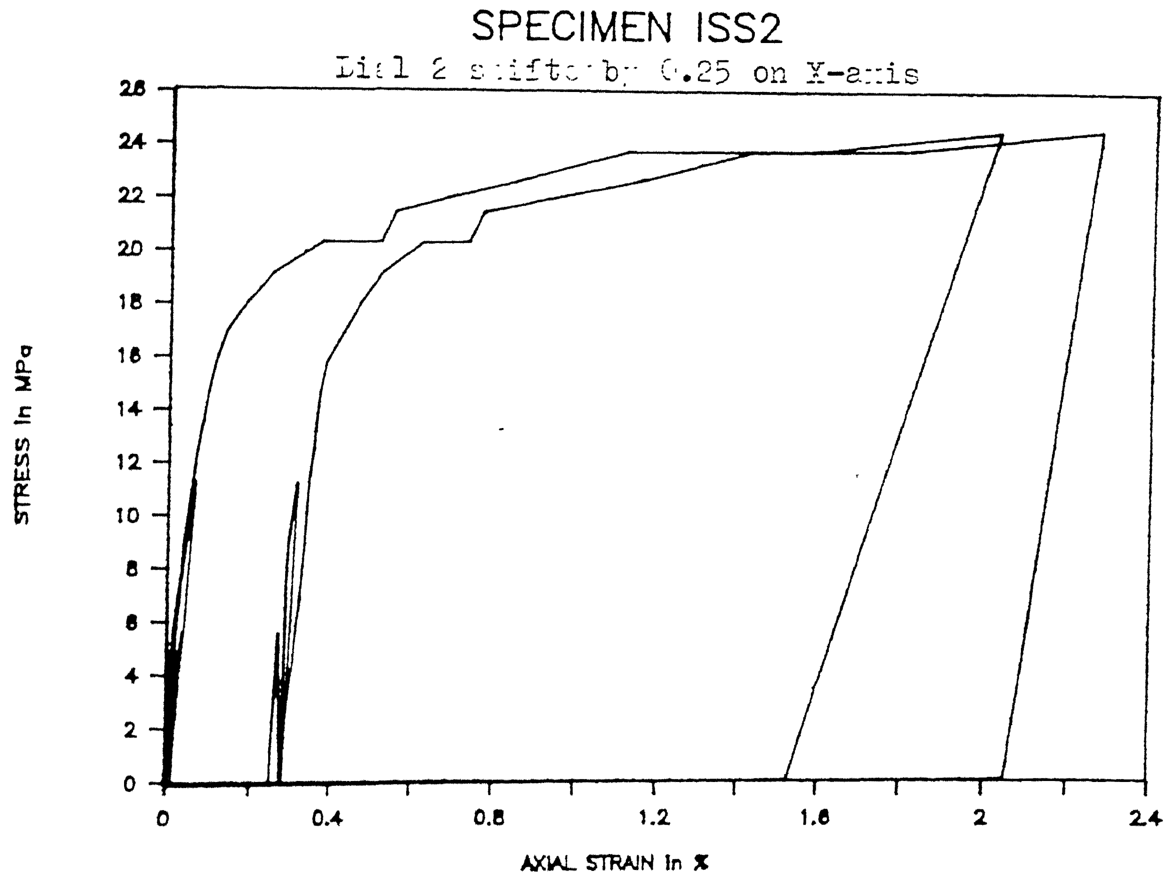


Figure :4.32 Plot of Stress-Strain for specimen - ISS2.

-spiral failed at the center of the specimen during bulging of concrete.

-sudden drop of the load from 43.25t was observed at failure

-in the post failure stage, the specimen was unloaded and residual shortening was recorded on the diametrically opposite sides of the specimens

-more settlement of the specimen was observed on the failed spiral side, which was further verified by the calculated strains

4.33 SPECIMEN ISS3:

-for this specimen first three load cycles were in the elastic range. This was further verified by the test results (table 4.33 & fig 4.33)

-during the testing at a load of 6t in the first cycle, load capacity decreased due to small end settlement and then regained,-strain of magnitude 0.002 was reached at a load of 31t.

-drop of load at 44t was observed in the fourth cycle with cracking of concrete

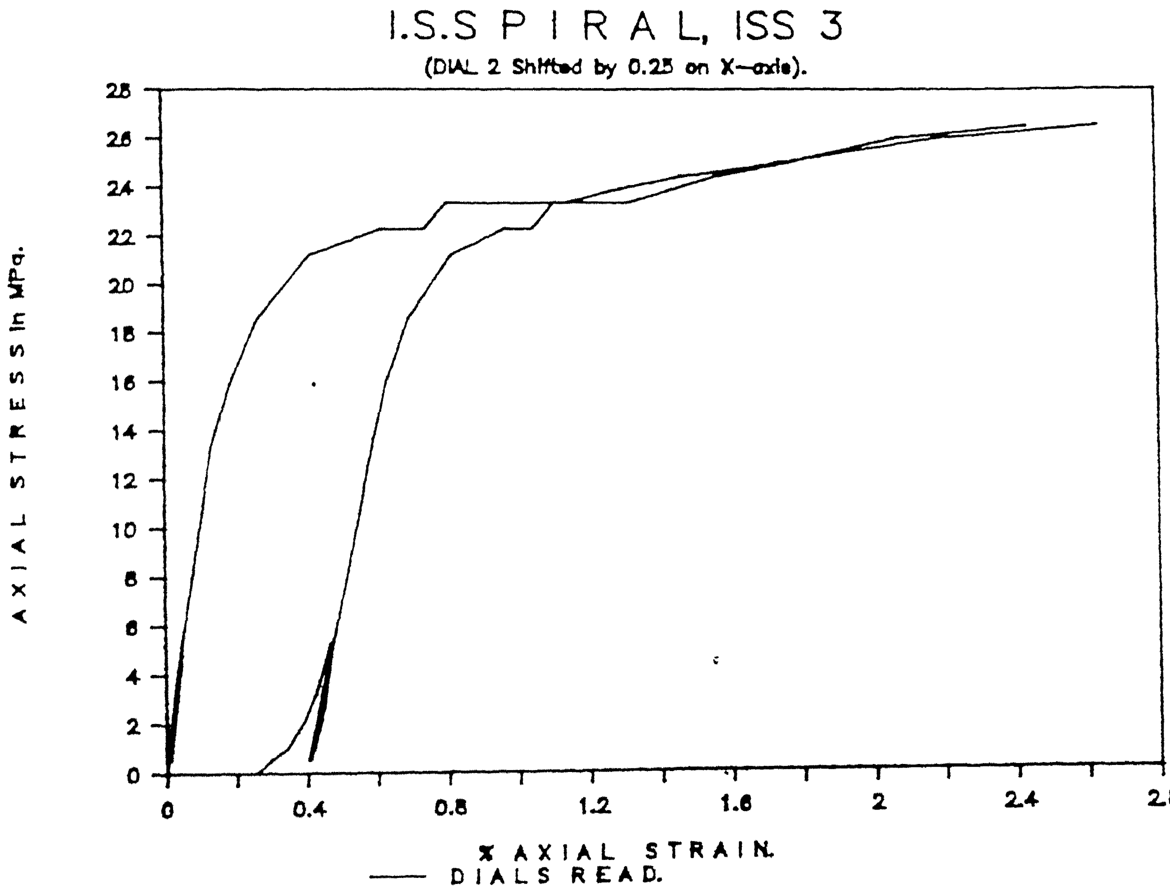
-cover failed completely and fell apart and plastic deformation started at about 42t load, strain increased from 0.006182 to 0.0114 with a load step of 2t.

-the strain at failure load was observed as 0.0264 in the central part and 0.0219 in the total length of the specimen.

TABLE 4.33 RESULTS OF LOADED SPECIMEN: ISS3

SNo	[LOAD,t	READINGS DIAL1	] DIAL2	STRESS in MPa	[%STRAINS] DIAL1	DIAL2	REMARKS
1	0.0	19.0	797.0	0.00	0.00	0.00	CYCLE 1
2	1.0	20.0	811.0	0.53	0.00	0.05	
3	2.0	21.0	826.0	1.06	0.01	0.09	
4	4.0	23.0	840.0	2.12	0.02	0.14	
5	6.0	25.0	850.0	3.18	0.03	0.17	
6	8.0	27.0	857.0	4.24	0.04	0.20	
7	10.0	30.0	864.0	5.30	0.05	0.22	
8	1.0	21.5	843.0	0.53	0.01	0.15	CYCLE 2
9	2.0	22.5	848.0	1.06	0.02	0.17	
10	4.0	24.5	854.0	2.12	0.03	0.19	
11	6.0	26.5	858.0	3.18	0.03	0.20	
12	8.0	28.5	862.0	4.24	0.04	0.21	
13	10.0	30.0	865.0	5.30	0.05	0.22	
14	1.0	21.5	845.0	0.53	0.01	0.16	CYCLE 3
15	2.0	22.5	848.5	1.06	0.02	0.17	
16	4.0	25.0	855.0	2.12	0.03	0.19	
17	6.0	27.0	859.0	3.18	0.04	0.20	
18	8.0	29.0	863.0	4.24	0.05	0.21	
19	10.0	30.0	865.5	5.30	0.05	0.22	
20	1.0	21.5	844.0	0.53	0.01	0.15	CYCLE 4
21	5.0	26.0	858.0	2.65	0.03	0.20	
22	10.0	30.0	866.0	5.30	0.05	0.22	
23	15.0	36.0	878.0	7.95	0.08	0.26	
24	20.0	42.5	890.0	10.60	0.11	0.30	
25	25.0	48.0	900.0	13.24	0.13	0.34	
26	30.0	60.0	913.0	15.89	0.19	0.38	
27	35.0	77.0	933.0	18.54	0.26	0.44	
28	40.0	110.0	971.0	21.19	0.41	0.57	
29	42.0	155.0	1017.0	22.25	0.62	0.72	
30	42.0	182.0	1041.0	22.25	0.74	0.79	
31	44.0	196.0	1060.0	23.31	0.80	0.86	
32	44.0	270.0	1125.0	23.31	1.14	1.07	CRACKING STARTED
33	45.0	300.0	1162.0	23.84	1.28	1.19	
34	46.0	340.0	1200.0	24.37	1.46	1.31	
35	47.0	400.0	1260.0	24.90	1.73	1.51	
36	49.0	500.0	1355.0	25.96	2.19	1.82	)MaX.LOAD, SPIRAL
37	50.0	600.0	1470.0	26.49	2.64	2.19	)FAILED

Figure : 4.33 Plot of Stress-Strain for specimen - ISS3.



-spiral failed at the center of the specimen and sudden drop of load from 50t was observed. One more spiral failed at a load of 15t. in the unloading stage.

4.4 SPECIMEN SET ISF:

Specimens of this set was tested in the same way as of ISS set and the failure patterns were observed to be similar to ISS set

4.5 SPECIMEN SET RFC:

In this test series specimens were marked as RFC1, RFC2 and RFC3. For all the specimens dial-1 and dial-2 were set for the total length of the specimen.

4.51 SPECIMEN RFC1:

-at a load of 14t specimen cracking was started

-the load reached a maximum of 16.75, then the load was released slowly to 12t.

-again the specimen was loaded till the spiral failed at a load of 15.25t and load dropped to 9.75t.

-load carrying capacity was built up upto 15.75t.

-at this point the specimen was unloaded and the residual strain was found to be 6.3%

-in the next loading phase, load reached a maximum value of 17.5t followed by a spiral failure and the load dropped to a level of 10.5t.

-the specimen continued taking load in the range of 10.5 to 12.0 tons with excessive deformations

TABLE 4.41 RESULTS OF LOADED SPECIMEN: ISF1

SNo	LOAD ton	[DIAL -1-	READ] -2-	STRESS[MPa	% MEAN	STRAIN -1-	] -2-	OBSERVATIONS
1	0.0	183	126	0.00	0.00	1.00	2.00	CYCLE I.
2	2.0	193	136	1.13	0.03	1.03	2.03	
3	4.0	207	148	2.26	0.08	1.08	2.07	
4	6.0	217	157	3.39	0.11	1.11	2.10	
5	8.0	225	165	4.53	0.13	1.14	2.13	
6	10.0	232	172	5.66	0.16	1.16	2.15	
7	12.0	238	178	6.79	0.18	1.18	2.17	UNLOADED
8	10.0	237	176	5.66	0.17	1.18	2.17	
9	8.0	234	172	4.53	0.16	1.17	2.15	
10	6.0	231	169	3.39	0.15	1.16	2.14	
11	4.0	227	166	2.26	0.14	1.15	2.13	
12	2.0	220	159	1.13	0.12	1.12	2.11	
13	0.0	185	130	0.00	0.01	1.01	2.01	CYCLE II.
14	2.0	210	154	1.13	0.09	1.09	2.09	
15.	4.0	218	160	2.26	0.12	1.12	2.11	
16	6.0	223	165	3.39	0.13	1.13	2.13	
17	8.0	227	169	4.53	0.15	1.15	2.14	
18	10.0	231	172	5.66	0.16	1.16	2.15	UNLOADED
19	8.0	230	171	4.53	0.15	1.16	2.15	
20	6.0	227	167	3.39	0.14	1.15	2.14	
21	4.0	222	163	2.26	0.13	1.13	2.12	
22	2.0	216	157	1.13	0.11	1.11	2.10	CYCLE III.
23	4.0	221	163	2.26	0.13	1.13	2.12	
24	6.0	229	168	3.39	0.15	1.15	2.14	
25	8.0	228	170	4.53	0.15	1.15	2.15	
26	10.0	229	171	5.66	0.15	1.15	2.15	
27	10.0	232	174	5.66	0.16	1.16	2.16	UNLOADED
28	8.0	231	171	4.53	0.15	1.16	2.15	
29	6.0	227	167	3.39	0.14	1.15	2.14	
30	4.0	223	163	2.26	0.13	1.13	2.12	
31	2.0	216	157	1.13	0.11	1.11	2.10	CYCLE IV.
32	4.0	222	163	2.26	0.13	1.13	2.12	
33	6.0	226	167	3.39	0.14	1.14	2.14	
34	8.0	229	170	4,53	0.15	1.15	2.15	
35	10.0	231	173	5.66	0.16	1.16	2.16	
36	12.0	236	177	6.79	0.17	1.18	2.17	
37	14.0	241	182	7.92	0.19	1.19	2.19	
38	15.0	245	185	8.48	0.20	1.21	2.20	
39	16.0	249	189	9.05	0.22	1.22	2.21	
40	18.0	256	196	10.18	0.24	1.24	2.23	
41	19.0	261	201	10.75	0.26	1.26	2.25	
42	20.0	266	206	11.31	0.27	1.28	2.27	

Table 4.41 (continued)

43	21.0	270	210	11.88	0.28	1.29	2.28	
44	22.0	276	215	12.44	0.30	1.31	2.30	
45	23.0	282	221	13.01	0.32	1.33	2.32	
46	24.0	288	227	13.58	0.34	1.35	2.34	
47	25.0	296	233	14.14	0.37	1.38	2.36	CRACKED
48	26.0	303	240	14.71	0.39	1.40	2.38	
49	27.0	313	249	15.27	0.42	1.43	2.41	
50	28.0	325	260	15.84	0.46	1.47	2.45	
51	29.0	337	273	16.40	0.50	1.51	2.49	
52	30.0	352	288	16.97	0.55	1.56	2.54	
53	31.0	366	303	17.54	0.60	1.61	2.59	
54	32.0	382	319	18.10	0.65	1.66	2.64	
55	33.0	399	335	18.67	0.71	1.72	2.70	
56	34.0	418	354	19.23	0.77	1.78	2.76	
57	35.0	442	376	19.80	0.85	1.86	2.83	
58	36.0	466	402	20.36	0.93	1.94	2.92	
59	37.0	499	436	20.93	1.04	2.05	3.03	
60	37.8	560	496	21.35	1.25	2.26	3.23	
61	39.0	569	506	22.06	1.28	2.29	3.27	ULTIMATE LOAD
62	38.8	650	587	21.92	1.55	2.56	3.54	SPIRAL FAILED
63	25.5	760	705	14.42	1.93	2.92	3.93	
64	27.0	797	740	15.27	2.05	3.05	4.05	
65	26.0	882	823	14.71	2.33	3.33	4.32	
66	26.0	940	880	14.71	2.52	3.52	4.51	
67	25.0	975	915	14.14	2.64	3.64	4.63	2nd SPIRAL FAILED
68	12.5	1025	962	7.07	2.80	3.81	4.79	CONTINUED LOADING.
69	12.8	1100	1037	7.21	3.05	4.06	5.04	
70	12.0	1190	1128	6.79	3.35	4.36	5.34	
71	11.0	1300	1236	6.22	3.71	4.72	5.70	
72	11.8	1400	1337	6.65	4.05	5.06	6.04	
73	11.5	1500	1435	6.51	4.38	5.39	6.36	
74	11.0	1600	1535	6.22	4.71	5.72	6.70	UNLOADED.
75	9.0	1640	1575	5.09	4.84	5.86	6.83	
76	6.0	1627	1562	3.39	4.80	5.81	6.79	
77	5.0	1619	1554	2.83	4.77	5.79	6.76	
78	4.0	1611	1546	2.26	4.75	5.76	6.73	
79	3.0	1598	1534	1.70	4.71	5.72	6.69	
80	2.0	1585	1521	1.13	4.66	5.67	6.65	
81	1.0	1546	1486	0.57	4.54	5.54	6.53	
82	0.5	1510	1468	0.28	4.45	5.42	6.47	

TABLE 4.42 RESULTS OF LOADED SPECIMEN: ISF2

SNo	LOAD	[DIAL	READ]	STRESS[	% STRAIN		]	OBSERVATIONS
	ton	-1-	-2-	MPa	MEAN	-1-	-2-	
1	0.0	436	411	0.00	0.00	1.00	2.00	
2	0.3	441	415	0.14	0.01	1.02	2.01	
3	2.0	470	444	1.13	0.11	1.11	2.11	
4	5.5	501	475	3.11	0.22	1.22	2.21	
5	7.0	510	484	3.96	0.24	1.25	2.24	
6	8.0	518	492	4.53	0.27	1.27	2.27	
7	9.0	525	500	5.09	0.30	1.30	2.30	
8	10.0	535	511	5.66	0.33	1.33	2.33	
9	11.0	564	545	6.22	0.44	1.43	2.45	
10	11.6	615	595	6.56	0.61	1.60	2.61	
11	11.8	655	635	6.65	0.74	1.73	2.75	
12	12.0	690	672	6.79	0.86	1.85	2.87	
13	12.3	710	690	6.93	0.92	1.91	2.93	
14	12.5	735	715	7.07	1.01	2.00	3.01	
15	12.8	760	742	7.21	1.09	2.08	3.10	
16	13.0	780	761	7.35	1.16	2.15	3.17	
17	13.3	820	798	7.49	1.29	2.28	3.29	
18	13.5	840	818	7.64	1.35	2.35	3.36	
19	13.8	865	847	7.78	1.44	2.43	3.45	
20	14.0	885	866	7.92	1.51	2.50	3.52	
21	14.5	934	911	8.20	1.66	2.66	3.67	
22	15.0	968	942	8.48	1.77	2.77	3.77	
23	15.5	997	976	8.77	1.88	2.87	3.88	
24	16.0	1034	1012	9.05	2.00	2.99	4.00	
25	16.5	1080	1059	9.33	2.15	3.15	4.16	
26	17.0	1135	1118	9.62	2.34	3.33	4.36	
27	18.0	1228	1208	10.18	2.65	3.64	4.66	
28	18.5	1300	1281	10.46	2.89	3.88	4.90	
29	19.0	1357	1338	10.75	3.08	4.07	5.09	CRACKED
30	19.5	1485	1463	11.03	3.50	4.50	5.51	
31	20.0	1545	1524	11.31	3.70	4.70	5.71	
32	20.3	1560	1540	11.45	3.76	4.75	5.76	Max. LOAD, SPIRAL
33	10.3	1710	1683	5.80	4.24	5.25	6.24	
34	11.3	1745	1722	6.36	4.37	5.36	6.37	
35	12.0	1787	1765	6.79	4.51	5.50	6.51	
36	12.5	1823	1799	7.07	4.63	5.62	6.63	
37	13.0	1857	1835	7.35	4.74	5.74	6.75	
38	13.5	860	1995	7.64	5.23	6.17	7.28	
39	11.0	847	2008	6.22	5.23	6.13	7.32	
40	9.0	843	2003	5.09	5.21	6.11	7.31	
41	8.3	841	2001	4.67	5.20	6.11	7.30	
42	8.0	838	1997	4.53	5.19	6.10	7.29	
43	5.0	829	1989	2.83	5.16	6.07	7.26	
44	4.0	824	1984	2.26	5.15	6.05	7.24	
45	3.0	816	1976	1.70	5.12	6.02	7.22	

Table 4.42 (continued)

46	2.0	805	1966	1.13	5.09	5.99	7.18	
47	1.0	882	1943	0.57	5.18	6.24	7.11	
48	0.5	858	1920	0.28	5.10	6.16	7.03	IInd CYCLE.
49	1.0	859	1924	0.57	5.11	6.17	7.04	
50	2.5	886	1951	1.41	5.20	6.26	7.13	
51	3.5	898	1961	1.98	5.23	6.30	7.17	
52	6.0	918	1979	3.39	5.30	6.36	7.23	
53	8.5	932	1993	4.81	5.34	6.41	7.27	
54	11.0	946	2007	6.22	5.39	6.46	7.32	
55	12.0	955	2016	6.79	5.42	6.49	7.35	
56	13.0	970	2031	7.35	5.47	6.54	7.40	
57	14.0	928	2089	7.92	5.50	6.40	7.59	
58	15.0	1075	2235	8.48	5.98	6.89	8.08	
59	15.3	1180	2341	8.63	6.34	7.24	8.43	
60	15.3	1240	1169	8.63	6.54	7.44	8.63	
61	16.0	1290	1219	9.05	6.70	7.60	8.80	
62	16.8	1420	1348	9.47	7.13	8.04	9.23	
63	18.0	1545	1473	10.18	7.55	8.45	9.65	
64	17.5	1670	1600	9.90	7.97	8.87	10.07	
65	17.4	1870	1798	9.84	8.63	9.54	10.73	LOAD REDUCED
66	12.5	1951	1878	7.07	8.90	9.81	11.00	
67	9.0	1944	1871	5.09	8.88	9.78	10.97	
68	7.0	1938	1865	3.96	8.86	9.76	10.95	
69	4.5	1925	1854	2.55	8.82	9.72	10.92	
70	4.0	1921	1850	2.26	8.81	9.71	10.90	IIIrd CYCLE.
71	6.0	1925	1854	3.39	8.82	9.72	10.92	
72	8.0	1932	1861	4.53	8.84	9.74	10.94	
73	11.0	1942	1870	6.22	8.87	9.78	10.97	
74	12.0	1946	1874	6.79	8.89	9.79	10.98	
75	14.0	1953	1881	7.92	8.91	9.81	11.01	
76	13.0	1959	1886	7.35	8.93	9.83	11.02	
77	16.0	1980	1908	9.05	9.00	9.90	11.10	
78	16.5	2050	1978	9.33	9.23	10.14	11.33	
79	16.0	2110	2040	9.05	9.44	10.34	11.54	
80	14.5	2385	2313	8.20	10.35	11.25	12.45	
81	14.8	2470	2398	8.34	10.63	11.54	12.73	LOAD REDUCED.
82	9.0	2492	2421	5.09	10.71	11.61	12.81	
83	7.0	2487	2416	3.96	10.69	11.59	12.79	
84	5.0	2476	2406	2.83	10.66	11.56	12.76	
85	3.0	2461	2391	1.70	10.61	11.51	12.71	
86	2.0	2449	2379	1.13	10.57	11.47	12.67	
87	1.0	2425	2355	0.57	10.49	11.39	12.59	
88	0.5	2400	2330	0.28	10.40	11.30	12.50	
89	0.3	2372	2293	0.14	10.30	11.21	12.38	
90	0.1	2200	2170	0.06	9.80	10.64	11.97	

TABLE 4.43 RESULTS OF LOADED SPECIMEN: ISF3

SNo	LOAD	[DIAL	READ]	STRESS[	% STRAIN		]	OBSERVATIONS
	ton	-1-	-2-	MPa	MEAN	-1-	-2-	
1	0.0	331	2196	0.00	0.00	1.00	2.00	
2	3.0	375	2209	1.70	0.10	1.15	2.04	
3	4.0	381	2215	2.26	0.12	1.17	2.06	
4	5.0	386	2220	2.83	0.13	1.18	2.08	
5	10.0	420	2249	5.66	0.24	1.30	2.18	
6	14.9	497	2426	8.40	0.66	1.55	2.77	
7	14.0	580	2508	7.92	0.94	1.83	3.04	
8	13.0	660	2588	7.35	1.20	2.10	3.31	
9	12.5	755	2677	7.07	1.51	2.41	3.60	
10	12.5	764	2688	7.07	1.54	2.44	3.64	
11	13.0	845	2773	7.35	1.82	2.71	3.92	
12	13.5	935	2865	7.64	2.12	3.01	4.23	
13	14.0	1025	2955	7.92	2.42	3.31	4.53	
14	14.5	1160	3090	8.20	2.87	3.76	4.98	
15	15.0	1317	3245	8.48	3.39	4.29	5.50	
16	15.5	1478	3408	8.77	3.93	4.82	6.04	
17	16.0	1563	3495	9.05	4.22	5.11	6.33	
18	16.5	1645	3573	9.33	4.49	5.38	6.59	
19	17.0	1725	3655	9.62	4.76	5.65	6.86	
20	17.7	1881	3732	10.01	5.14	6.17	7.12	
21	18.0	1910	3862	10.18	5.41	6.26	7.55	
22	18.3	1995	3943	10.32	5.69	6.55	7.82	
23	18.5	2147	4103	10.46	6.21	7.05	8.36	
24	18.8	2180	4135	10.61	6.31	7.16	8.46	
25	18.9	2270	4225	10.69	6.61	7.46	8.76	
26	19.0	2400	4356	10.75	7.05	7.90	9.20	
27	19.3	2500	4455	10.89	7.38	8.23	9.53	
28	0.0	485	404	0.00	7.38	8.23	9.53	
29	5.0	511	430	2.83	7.47	8.32	9.62	
30	10.0	575	495	5.66	7.68	8.53	9.83	
31	15.0	661	582	8.48	7.97	8.82	10.12	
32	16.0	705	626	9.05	8.12	8.96	10.27	
33	17.0	765	686	9.62	8.32	9.16	10.47	
34	18.0	895	816	10.18	8.75	9.60	10.90	
35	18.5	1015	936	10.46	9.15	10.00	11.30	
36	18.7	1110	1030	10.55	9.47	10.31	11.62	
37	19.0	1180	1101	10.75	9.70	10.55	11.85	
38	19.0	1250	1170	10.75	9.93	10.78	12.08	
39	15.0	1410	1330	8.48	10.47	11.31	12.62	
40	16.1	1530	1450	9.11	10.87	11.71	13.02	
41	16.0	1590	1512	9.05	11.07	11.91	13.22	
42	16.0	1710	1632	9.05	11.47	12.31	13.62	
43	16.0	1770	1692	9.05	11.67	12.51	13.82	
44	16.2	1860	1782	9.14	11.97	12.81	14.12	
45	16.0	1970	1891	9.05	12.33	13.18	14.49	
46	16.2	2020	1942	9.14	12.50	13.35	14.66	
47	16.5	2125	2045	9.33	12.85	13.70	15.00	
48	16.8	2240	2161	9.50	13.23	14.08	15.39	
49	16.8	2340	2262	9.50	13.57	14.41	15.72	
50	17.1	2510	2435	9.67	14.14	14.98	16.30	

TABLE 4.51 RESULTS OF LOADED SPECIMEN: RFC1

SNo	[LOADt	READINGS DIAL1	] DIAL2	STRESS MPa.	[% MEAN	STRAINS DIAL1	] DIAL2
1	0	140	103	0.00	0.000	1.000	2.000
2	4	160	128	2.26	0.075	1.067	2.083
3	5	164	134	2.83	0.092	1.080	2.103
4	10	199	171	5.66	0.212	1.197	2.227
5	12	216	186	6.79	0.265	1.253	2.277
6	13	225	196	7.35	0.297	1.283	2.310
7	15	247	218	8.48	0.370	1.357	2.383
8	16	265	237	9.05	0.432	1.417	2.447
9	16.75	302	275	9.47	0.557	1.540	2.573
10	16.4	307	281	9.28	0.575	1.557	2.593
11	16.2	337	309	9.16	0.672	1.657	2.687
12	15	394	364	8.48	0.858	1.847	2.870
13	14.25	432	398	8.06	0.978	1.973	2.983
14	14	460	424	7.92	1.068	2.067	3.070
15	13.75	490	454	7.78	1.168	2.167	3.170
16	13.5	497	462	7.64	1.193	2.190	3.197
17	13.25	533	493	7.49	1.305	2.310	3.300
18	13	560	519	7.35	1.393	2.400	3.387
19	13	600	561	7.35	1.530	2.533	3.527
20	13	658	619	7.35	1.723	2.727	3.720
21	12.5	700	663	7.07	1.867	2.867	3.867
22	12.5	750	711	7.07	2.030	3.033	4.027
23	12.5	768	729	7.07	2.090	3.093	4.087
24	12.75	845	807	7.21	2.348	3.350	4.347
25	12.75	893	856	7.21	2.510	3.510	4.510
26	12.75	920	881	7.21	2.597	3.600	4.593
27	13.25	980	942	7.49	2.798	3.800	4.797
28	13.5	1020	980	7.64	2.928	3.933	4.923
29	14	1120	1081	7.92	3.263	4.267	5.260
30	14.25	1180	1141	8.06	3.463	4.467	5.460
31	14.5	1230	1190	8.20	3.628	4.633	5.623
32	14.75	1280	1240	8.34	3.795	4.800	5.790
33	15.25	1370	1330	8.63	4.095	5.100	6.090
34	9.75	1430	1390	5.52	4.295	5.300	6.290
35	10	1460	1421	5.66	4.397	5.400	6.393
36	10.25	1490	1454	5.80	4.502	5.500	6.503
37	10.75	1520	1483	6.08	4.600	5.600	6.600
38	11	1540	1503	6.22	4.667	5.667	6.667
39	11	1575	1539	6.22	4.785	5.783	6.787
40	11.75	1600	1567	6.65	4.873	5.867	6.880

* Dial 1 and Dial 2 strains are started from 1% and 2% respectively.

TABLE 4.51 (CONTD.) SPECIMEN: RFC1

SNo	[LOADt	READINGS DIAL1	] DIAL2	STRESS MPa.	[% MEAN	STRAINS DIAL1	] DIAL2
41	12	1640	1607	6.79	5.007	6.000	7.013
42	13.5	1825	1793	7.64	5.625	6.617	7.633
43	14.5	1905	1875	8.20	5.895	6.883	7.907
44	15	1960	1928	8.48	6.075	7.067	8.083
45	15.5	2000	1963	8.77	6.200	7.200	8.200
46	15.75	2050	2008	8.91	6.358	7.367	8.350
47	13.5	2124	2181	7.64	6.770	7.613	8.927
48	7	2110	2167	3.96	6.723	7.567	8.880
49	5	2093	2152	2.83	6.670	7.510	8.830
50	4	1985	2046	2.26	6.313	7.150	8.477
51	0	204	156	0.00	6.313	7.150	8.477
52	5	219	171	2.83	6.363	7.200	8.527
53	8	250	198	4.53	6.460	7.303	8.617
54	11	280	229	6.22	6.562	7.403	8.720
55	13	325	275	7.35	6.713	7.553	8.873
56	14	375	326	7.92	6.882	7.720	9.043
57	15	490	442	8.48	7.267	8.103	9.430
58	15.5	590	542	8.77	7.600	8.437	9.763
59	16	710	664	9.05	8.00	8.84	10.17
60	17.5	900	858	9.90	8.64	9.47	10.82
61	10.5	1180	1140	5.94	9.58	10.40	11.76
62	11.5	1265	1220	6.51	9.86	10.69	12.02
63	11.5	1365	1320	6.51	10.19	11.02	12.36
64	11.5	1435	1389	6.51	10.42	11.25	12.59
65	11.75	1495	1450	6.65	10.62	11.45	12.79
66	11.5	1605	1560	6.51	10.99	11.82	13.16
67	12	1750	1705	6.79	11.47	12.30	13.64
68	11.75	1840	1795	6.65	11.77	12.60	13.94
69	11	2070	2024	6.22	12.54	13.37	14.70
70	2	2000	2055	1.13	12.47	13.14	14.81

4.52 SPECIMEN RFC2:

-at a load of 21.5t specimen cracking was started

-the load reached a maximum of 21.55t

-specimen was loaded till the spiral failed at a load of 21t and load dropped to 15t with a strain increase of 0.015%

-at this point the specimen was unloaded and the residual strain was found to be 0.78%

-in the next loading phase, load varied between 19.5t to 21.25t with a strain of about 3.1%

-this followed by a spiral failure and the load dropped to a level of 8.5t.with a strain increase of 0.78%

-at this point load on the specimen was released and the residual strain was found to be 3.62%

4.53 SPECIMEN RFC3:

-at a load of 24t specimen cracking was started and the load reached a maximum of 27t at a strain of 0.69 to 1.02 percent

-cracks became wider after maximum load but the cover concrete was held in position by the fibers

-load capacity of the specimen regained due to the spiral confining action, reached a maximum of 26.75t

-at this point the specimen was unloaded to 0.75t. and the residual strain was found to be 1.13%

-in the next phase the specimen was loaded till the spiral

TABLE 4.52 RESULTS OF LOADED SPECIMEN: RFC2

SNo	[LOADt	READINGS DIAL1	] DIAL2	STRESS MPa.	[% MEAN	STRAINS DIAL1	] DIAL2
1	0	377	336	0.00	0.000	1.000	2.000
2	2	385	346	1.13	0.030	1.027	2.033
3	4	394	357	2.26	0.063	1.057	2.070
4	6	402	365	3.39	0.090	1.083	2.097
5	8	410	372	4.53	0.115	1.110	2.120
6	10	417	379	5.66	0.138	1.133	2.143
7	11	422	384	6.22	0.155	1.150	2.160
8	12	425	387	6.79	0.165	1.160	2.170
9	13	429	391	7.35	0.178	1.173	2.183
10	14	434	395	7.92	0.193	1.190	2.197
11	15	439	400	8.48	0.210	1.207	2.213
12	16	445	406	9.05	0.230	1.227	2.233
13	17	451	412	9.62	0.250	1.247	2.253
14	18	460	421	10.18	0.280	1.277	2.283
15	19	471	432	10.75	0.317	1.313	2.320
16	20	486	447	11.31	0.367	1.363	2.370
17	20.5	501	463	11.60	0.418	1.413	2.423
18	21	513	476	11.88	0.460	1.453	2.467
19	21.5	528	490	12.16	0.508	1.503	2.513
20	21.5	595	558	12.16	0.733	1.727	2.740
21	21.55	640	604	12.19	0.885	1.877	2.893
22	21.3	670	636	12.05	0.988	1.977	3.000
23	21	697	664	11.88	1.080	2.067	3.093
24	15	702	668	8.48	1.095	2.083	3.107
25	12	694	661	6.79	1.070	2.057	3.083
26	10	687	655	5.66	1.048	2.033	3.063
27	9	683	651	5.09	1.035	2.020	3.050
28	8	679	647	4.53	1.022	2.007	3.037
29	7	674	642	3.96	1.005	1.990	3.020
30	6	669	637	3.39	0.988	1.973	3.003
31	5	662	630	2.83	0.965	1.950	2.980
32	4	655	622	2.26	0.940	1.927	2.953
33	3	644	610	1.70	0.902	1.890	2.913
34	2	631	596	1.13	0.857	1.847	2.867
35	1	607	574	0.57	0.780	1.767	2.793
36	3	625	591	1.70	0.838	1.827	2.850
37	5	640	606	2.83	0.888	1.877	2.900
38	6	648	614	3.39	0.915	1.903	2.927
39	8	660	625	4.53	0.953	1.943	2.963
40	10	674	640	5.66	1.002	1.990	3.013

$ Dial 1 and Dial 2 strains are started from 1% and 2% respectively.

TABLE 4.52 (CONTD.) SPECIMEN: RFC2

SNo	[LOADt	READINGS DIAL1	] DIAL2	STRESS MPa.	[% MEAN	STRAINS DIAL1	] DIAL2
41	12	681	647	6.79	1.025	2.013	3.037
42	14	690	656	7.92	1.055	2.043	3.067
43	15	694	660	8.48	1.068	2.057	3.080
44	16	699	665	9.05	1.085	2.073	3.097
45	18	711	676	10.18	1.123	2.113	3.133
46	19	720	685	10.75	1.153	2.143	3.163
47	19.5	726	691	11.03	1.173	2.163	3.183
48	20	736	701	11.31	1.207	2.197	3.217
49	20.5	760	726	11.60	1.288	2.277	3.300
50	21	780	747	11.88	1.357	2.343	3.370
51	21.25	850	813	12.02	1.583	2.577	3.590
52	21.25	900	866	12.02	1.755	2.743	3.767
53	21	940	906	11.88	1.888	2.877	3.900
54	21.25	1005	971	12.02	2.105	3.093	4.117
55	21.25	1070	1036	12.02	2.322	3.310	4.333
56	21	1130	1097	11.88	2.523	3.510	4.537
57	21	1200	1167	11.88	2.757	3.743	4.770
58	21.25	1305	1272	12.02	3.107	4.093	5.120
59	8.5	1360	1326	4.81	3.288	4.277	5.300
60	9.5	1460	1425	5.37	3.620	4.610	5.630
61	10	1550	1516	5.66	3.922	4.910	5.933
62	8	1573	1538	4.53	3.997	4.987	6.007
63	6	1565	1530	3.39	3.970	4.960	5.980
64	5	1560	1525	2.83	3.953	4.943	5.963
65	4	1552	1517	2.26	3.927	4.917	5.937
66	3	1542	1507	1.70	3.893	4.883	5.903
67	2	1526	1491	1.13	3.840	4.830	5.850
68	1	1490	1455	0.57	3.720	4.710	5.730
69	0.5	1460	1426	0.28	3.622	4.610	5.633

TABLE 4.53 RESULTS OF LOADED SPECIEN RFC3

	[------- READINGS	----------][--------		% STRAIN	--------]		STRESS
SNo	LOAD t	DIAL 1	DIAL 2	MEAN	DIAL 1	DAIL 2	MPa
1	0	65	31	0	1	2	0
2	2	86	47	0.0617	1.07	2.0533	1.1313
3	4	97	57	0.0967	1.1067		2.2626
4	6	106	66	0.1267	1.1367	2.1167	3.3939
5	8	113	74	0.1517	1.16	2.1433	4.5253
6	10	120	80	0.1733	1.1833	2.1633	5.6566
7	12	126	87	0.195	1.2033	2.1867	6.7879
8	14	134	95	0.2217	1.23	2.2133	7.9192
9	16	141	102	0.245	1.2533	2.2367	9.0505
10	18	149	110	0.2717	1.28	2.2633	10.1818
11	20	159	120	0.305	1.3133	2.2967	11.3131
12	22	172	132	0.3467	1.3567	2.3367	12.4444
13	24	190	149	0.405	1.4167	2.3933	13.5758
14	26	235	190	0.5483	1.5667	2.53	14.7071
15	27	280	230	0.69	1.7167	2.6633	15.2727
16	27	330	278	0.8533	1.8833	2.8233	15.2727
17	27	380	328	1.02	2.05	2.99	15.2727
18	26	405	354	1.105	2.1333	3.0767	14.7071
19	24	410	356	1.1167	2.15	3.0833	13.5758
20	21	406	352	1.1033	2.1367	3.07	11.8788
21	20	403	350	1.095	2.1267	3.0633	11.3131
22	21	405	352	1.1017	2.1333	3.07	11.8788
23	22	406	353	1.105	2.1367	3.0733	12.4444
24	25	413	360	1.1283	2.16	3.0967	14.1414
25	26.5	425	372	1.1683	2.2	3.1367	14.9899
26	26.75	455	402	1.2683	2.3	3.2367	15.1313
27	26.75	505	452	1.435	2.4667	3.4033	15.1313
28	22	517	462	1.4717	2.5067	3.4367	12.4444
29	17	508	454	1.4433	2.4767	3.41	9.6162
30	15	504	450	1.43	2.4633	3.3967	8.4848
31	13	500	446	1.4167	2.45	3.3833	7.3535
32	11		440	1.3967	2.43	3.3633	6.2222
33	10	491	437	1.3867	2.42	3.3533	5.6566
34	9	487	433	1.3733	2.4067	3.34	5.0909
35	8	484	430	1.3633	2.3967	3.33	4.5253
36	6	476	423	1.3383	2.37	3.3067	3.3939
37	5	471	418	1.3217	2.3533	3.29	2.8283
38	4	464	411	1.2983	2.33	3.2667	2.2626
39	3	457	304	1.1083	2.3067	2.91	1.697
40	2	447	393	1.24	2.2733	3.2067	1.1313

Table 4.53 (continued)

41	1	427	374	1.1750	2.2067	3.1433	0.5657
42	0.75	413	363	1.1333	2.1600	3.1067	0.4242
43	1	41	365	0.5167	0.9200	3.1133	0.5657
44	2	423	373	1.1667	2.1933	3.1400	1.1313
45	3	431	379	1.1900	2.2200	3.1600	1.6970
46	4	438	386	1.2133	2.2433	3.1833	2.2626
47	5	444	392	1.2333	2.2633	3.2033	2.8283
48	6	449	397	1.2500	2.2800	3.2200	3.3939
49	8	459	407	1.2833	2.3133	3.2533	4.5253
50	10	467	415	1.3100	2.3400	3.2800	5.6566
51	12	477	424	1.3417	2.3733	3.3100	6.7879
52	15	488	435	1.3783	2.4100	3.3467	8.4848
53	16	495	442	1.4017	2.4333	3.3700	9.0505
54	20	505	452	1.4350	2.4667	3.4033	11.3131
55	22	515	462	1.4683	2.5000	3.4367	12.4444
56	24	530	476	1.5167	2.5500	3.4833	13.5758
57	26	585	532	1.7017	2.7333	3.6700	14.7071
58	25	622	569	1.8250	2.8567	3.7933	14.1414
59	25.25	675	623	2.0033	3.0333	3.9733	14.2828
60	25.25	730	678	2.1867	3.2167	4.1567	14.2828
61	25.25	800	750	2.4233	3.4500	4.3967	14.2828
62	11.5	945	895	2.9067	3.9333	4.8800	6.5051
63	13	1000	951	3.0917	4.1167	5.0667	7.3535
64	12.25	1085	1036	3.3750	4.4000	5.3500	6.9293
65	12.75	1190	1140	3.7233	4.7500	5.6967	7.2121
66	13.5	1300	1251	4.0917	5.1167	6.0667	7.6364
67	11	1340	1290	4.2233	5.2500	6.1967	6.2222
68	8	1332	1281	4.1950	5.2233	6.1667	4.5253
69	6	1323	1281	4.1800	5.1933	6.1667	3.3939
70	5	1318	1268	4.1500	5.1767	6.1233	2.8283
71	7	1320	1270	4.1567	5.1833	6.1300	3.9596
72	10	1330	1280	4.1900	5.2167	6.1633	5.6566
73	13	1345	1296	4.2417	5.2667	6.2167	7.3535
74	14	1415	1365	4.4733	5.5000	6.4467	7.9192
75	15	1530	1480	4.8567	5.8833	6.8300	8.4848
76	15.25	1630	1580	5.1900	6.2167	7.1633	8.6263
77	14.75	1800	1751	5.7583	6.7833	7.7333	8.3434
78	14	1860	1812	5.9600	6.9833	7.9367	7.9192
79	13	1960	1910	6.2900	7.3167	8.2633	7.3535
80	12	2020	1970	6.4900	7.5167	8.4633	6.7879
81	11	2105	2056	6.7750	7.8000	8.7500	6.2222
82	10	2270	2222	7.3267	8.3500	9.3033	5.6566
83	10	2340	2291	7.5583	8.5833	9.5333	5.6566
84	9	2368	2319	7.6517	8.6767	9.6267	5.0909
85	7	2366	2317	7.6450	8.6700	9.6200	3.9596
86	6	2363	2314	7.6350	8.6600	9.6100	3.3939
87	5	2359	2310	7.6217	8.6467	9.5967	2.8283
88	4	2353	2304	7.6017	8.6267	9.5767	2.2626
89	3	2346	2296	7.5767	8.6033	9.5500	1.6970
90	2	2334	2284	7.5367	8.5633	9.5100	1.1313
91	1	2315	2266	7.4750	8.5000	9.4500	0.5657
92	0.5	2293	2245	7.4033	8.4267	9.3800	0.2828
93	0.25	2267	2225	7.3267	8.3400	9.3133	0.1414

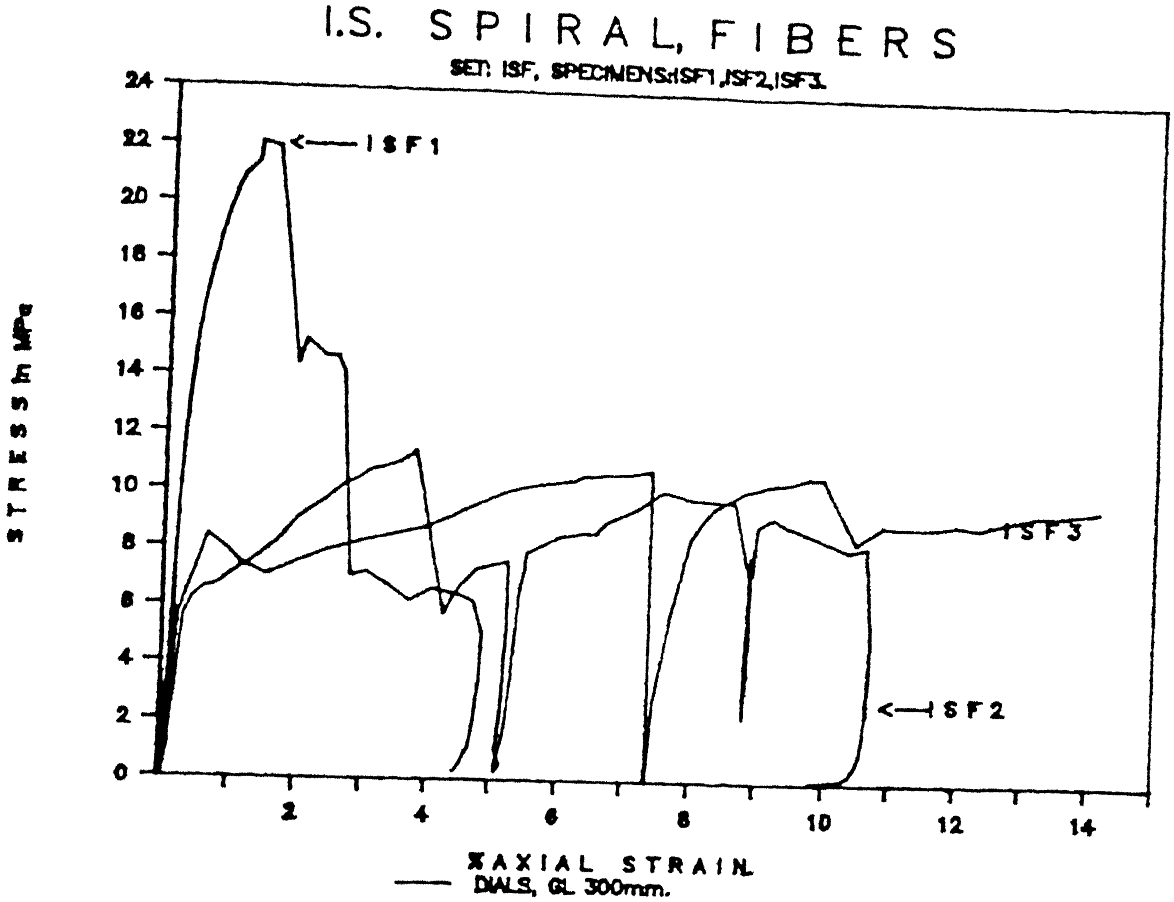


Figure 4.41 Plot of Stress-Strain for set ISF.

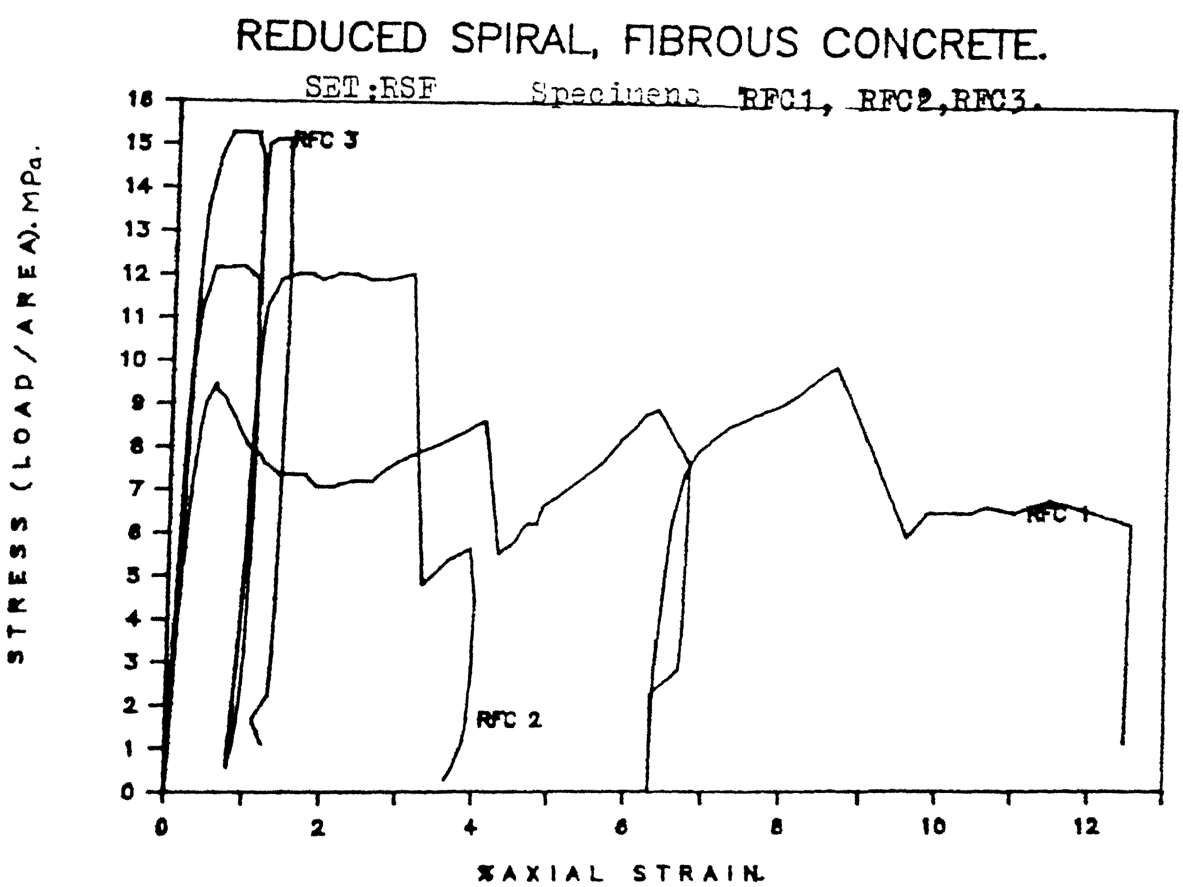


Figure 4.51 plot of Stress-strain of set RFC.

failed at a load of 25.25t. and load dropped to 11.5t.

-load carrying capacity was built up upto 15.25t.(about 70% of spiral failed load)

-the specimen continued taking load in the range of 11.5 to 13.5 tons with large deformations

-when the specimen was unloaded from 9t. to 1t. a reduction of the order of 0.3% was observed

4.6 SPECIMEN HFC:

-specimen cracked at a strain of 0.0052 for a load of 22t

-ultimate load was reached at a load of 26t

-one of the hoops started opening at ultimate load

-load decreased considerably after hoop opening was complete

4.7 SPECIMEN PFC:

-specimen started cracking at 22t with very low strain (0.22%) compared to the other fibrous concrete specimens

- the failure load was 24t with a strain of 0.49 percent.

TABLE 4.61 SPECIMEN:HFC

	LOAD t	[DIAL READS] -1-	-2-	STRESS MPa.	[% STRAINS MEAN	-1-	-2-]	REMARKS
1	0.0	142.0	29.0	0.00	0.00	1.00	2.00	
2	2.0	166.0	44.0	1.13	0.06	1.08	2.05	
3	4.0	179.0	53.0	2.26	0.10	1.12	2.08	
4	6.0	189.0	63.0	3.39	0.14	1.16	2.11	
5	8.0	200.0	72.0	4.53	0.17	1.19	2.14	
6	10.0	212.0	81.0	5.66	0.20	1.23	2.17	
7	12.0	224.0	92.0	6.79	0.24	1.27	2.21	
8	14.0	236.0	103.0	7.92	0.28	1.31	2.25	
9	16.0	247.0	114.0	9.05	0.32	1.35	2.28	
10	18.0	261.0	128.0	10.18	0.36	1.40	2.33	
11	20.0	279.0	144.0	11.31	0.42	1.46	2.38	
12	22.0	309.0	174.0	12.44	0.52	1.56	2.48	CRACKED
13	23.4	540.0	420.0	13.24	1.32	2.33	3.30	COVER FAILED
14	23.0	700.0	581.0	13.01	1.85	2.86	3.84	
15	24.0	755.0	637.0	13.58	2.04	3.04	4.03	
16	25.0	850.0	731.0	14.14	2.35	3.36	4.34	
17	25.8	970.0	854.0	14.57	2.76	3.76	4.75	
18	26.0	1060.0	943.0	14.71	3.05	4.06	5.05	ULTIMATE load,
19	26.0	1180.0	1064.0	14.71	3.46	4.46	5.45	Hoop opened
20	26.0	1260.0	1144.0	14.71	3.72	4.73	5.72	
21	25.8	1355.0	1237.0	14.57	4.04	5.04	6.03	
22	25.0	1420.0	1301.0	14.14	4.25	5.26	6.24	
23	24.8	1520.0	1402.0	14.00	4.59	5.59	6.58	
24	24.0	1620.0	1501.0	13.58	4.92	5.93	6.91	
25	22.0	1760.0	1642.0	12.44	5.39	6.39	7.38	
26	21.0	1840.0	1722.0	11.88	5.65	6.66	7.64	
27	20.0	1990.0	1864.0	11.31	6.14	7.16	8.12	
28	18.8	2120.0	1995.0	10.61	6.57	7.59	8.55	
29	18.5	2210.0	2092.0	10.46	6.89	7.89	8.88	
30	18.0	2275.0	2157.0	10.18	7.10	8.11	9.09	
31	18.0	2310.0	2291.0	10.18	7.38	8.23	9.54	
32	18.0	2360.0	2341.0	10.18	7.55	8.39	9.71	
33	18.0	2450.0	2329.0	10.18	7.68	8.69	9.67	
34	2.0	2430.0	2309.0	1.13	7.61	8.63	9.60	
35	1.0	2400.0	2283.0	0.57	7.52	8.53	9.51	

Dial 1 an Dial 2 values are started from 1.0% and 2.0% respectively.

TABLE 4.71 RESULTS OF LOADED SPECIMEN:PFC

SNo	LOAD t	[DIAL READS] -1-	-2-	STRESS MPa.	[% STRAINS MEAN	-1-	-2-]	REMARKS
1	0.0	158.0	454.0	0.00	0.00	1.00	2.00	
2	2.0	172.0	455.0	1.13	0.03	1.05	2.00	
3	4.0	181.0	457.0	2.26	0.04	1.08	2.01	
4	6.0	188.0	456.0	3.39	0.05	1.10	2.01	
5	8.0	195.0	456.0	4.53	0.07	1.12	2.01	
6	8.0	197.0	456.0	4.53	0.07	1.13	2.01	
7	10.0	203.0	457.0	5.66	0.08	1.15	2.01	
8	12.0	211.0	459.0	6.79	0.10	1.18	2.02	
9	14.0	220.0	461.0	7.92	0.12	1.21	2.02	
10	16.0	228.0	463.5	9.05	0.13	1.23	2.03	
11	18.0	236.0	466.0	10.18	0.15	1.26	2.04	
12	20.0	243.0	468.0	11.31	0.17	1.28	2.05	
13	20.0	250.0	470.0	11.31	0.18	1.31	2.05	
14	22.0	271.0	473.5	12.44	0.22	1.38	2.07	CRACKS ON
15	24.0	354.0	486.0	13.58	0.38	1.65	2.11	SURFACE
16	0.0	165.0	468.5	0.00	0.04	1.02	2.05	
17	16.0	367.0	505.0	9.05	0.43	1.70	2.17	
18	24.0	399.0	508.5	13.58	0.49	1.80	2.18	ULTIMATE.
19	24.0	585.0	510.0	13.58	0.81	2.42	2.19	
20	20.0	650.0	565.0	11.31	1.01	2.64	2.37	
21	19.0	730.0	595.0	10.75	1.19	2.91	2.47	
22	18.0	850.0	680.0	10.18	1.59	3.31	2.87	
23	17.0	995.0	740.0	9.62	1.93	3.79	3.07	
24	16.5	1020.0	870.0	9.33	2.19	3.87	3.50	
25	16.5	1085.0	940.0	9.33	2.41	4.09	3.74	
26	16.0	1195.0	1040.0	9.05	2.76	4.46	4.07	
27	16.0	1286.0	1140.0	9.05	3.08	4.76	4.40	
28	15.5	1330.0	1180.0	8.77	3.22	4.91	4.54	
29	15.3	1390.0	1230.0	8.63	3.41	5.11	4.70	
30	15.0	1412.0	1250.0	8.48	3.48	5.18	4.77	
31	14.8	1475.0	1310.0	8.34	3.68	5.39	4.97	
32	14.0	1537.0	1360.0	7.92	3.87	5.60	5.14	
33	13.0	1640.0	1455.0	7.35	4.20	5.94	5.45	
34	12.0	1747.0	1557.0	6.79	4.55	6.30	5.79	
35	11.0	1885.0	1700.0	6.22	5.01	6.76	6.27	
36	10.0	1965.0	1775.0	5.66	5.27	7.02	6.52	
37	9.5	2080.0	1910.0	5.37	5.69	7.41	6.97	
38	9.3	2130.0	1970.0	5.23	5.87	7.57	7.17	
39	9.0	2158.0	2000.0	5.09	5.97	7.67	7.27	
40	8.0	2330.0	2170.0	4.53	6.54	8.24	7.84	
41	8.0	2400.0	2239.0	4.53	6.77	8.47	8.07	
42	7.8	2450.0	2291.0	4.38	6.94	8.64	8.24	
43	7.5	2595.0	2433.0	4.24	7.42	9.12	8.71	

Dial 1 and Dial 2 values are started from 1.0% and 2.0% respectively.

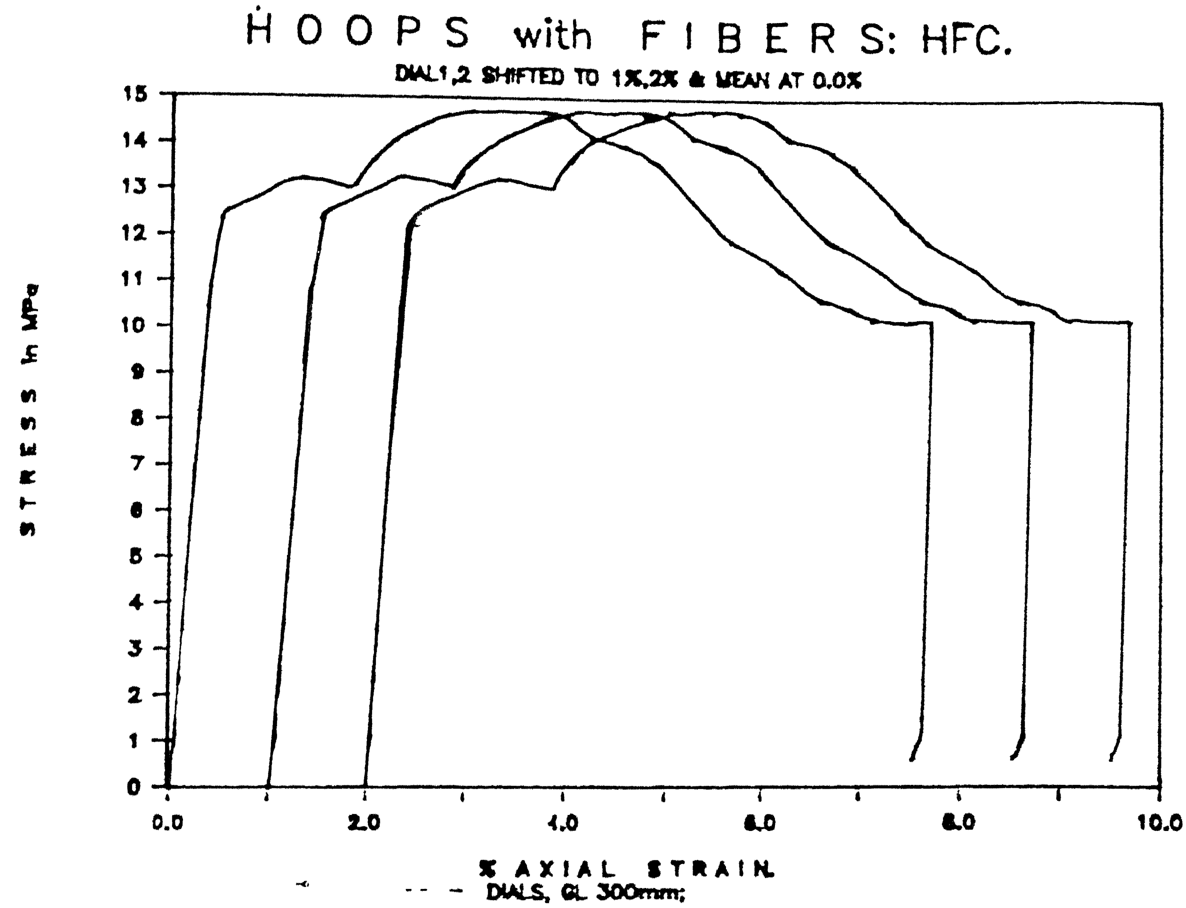


Figure 4.61: Plot of stress-strain for specimen HFC.

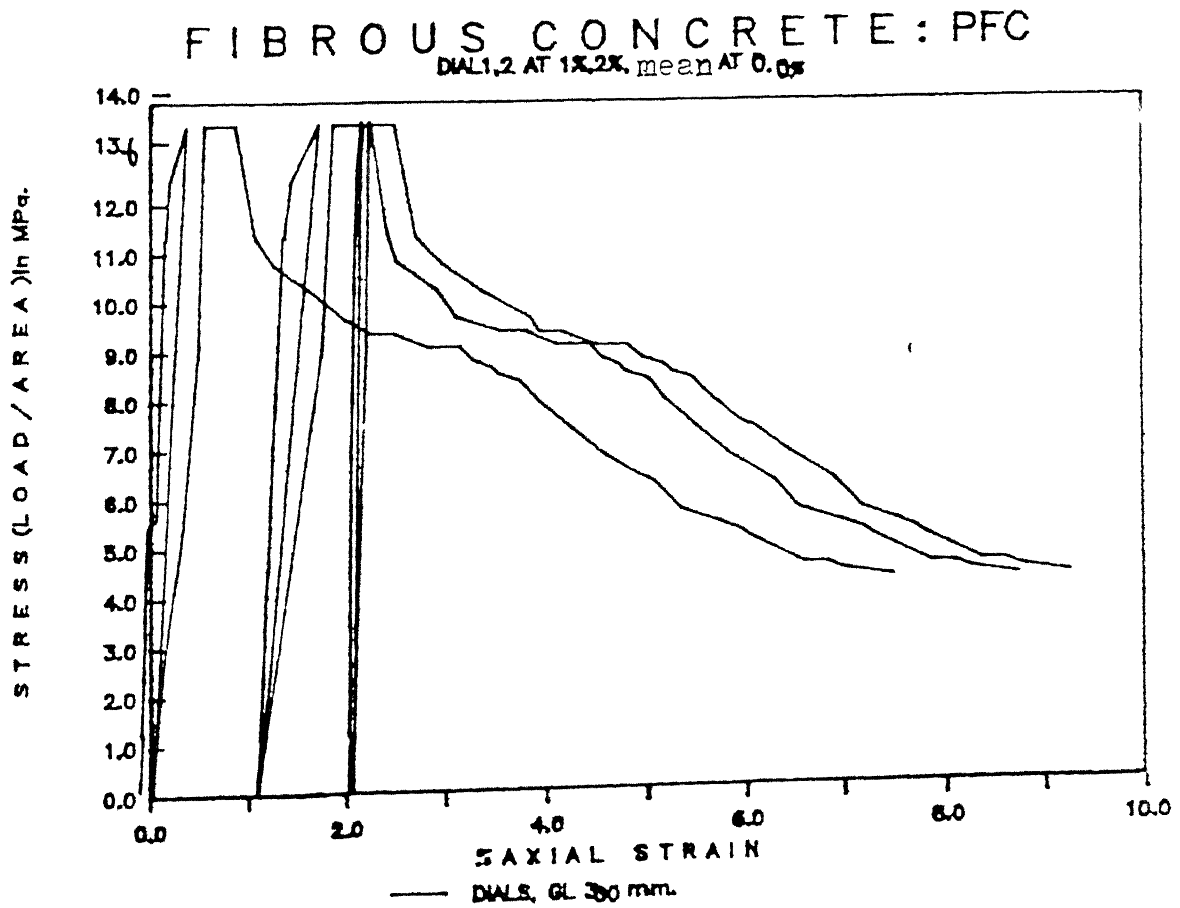


Figure 4.71: Plot of Stress-Strain for specimen PFC

5. ANALYSIS OF TEST RESULTS.

A brief summary and salient points of the physical and loading observations are illustrated in the Table 5.1. From the results obtained the following analysis has been done for various specimens.

5.1 SPECIMEN SET PCC:

Specimen of this set were tested at an age of 28, 41, 44 and 45 days, in one or two load cycles as the case may be. The increasing trend of the load carrying capacity with age was observed. For PCC1, PCC2 and PCC4 an average residual shortening of 0.05% was observed after the specimen were unloaded from a load level of 24t. For PCC2 when the load was kept constant at 28t., strain increased plastically. Ultimate load taken by this specimen was with a strain of 0.85%, more than double the ultimate strain of PCC1 and PCC4.

All the specimens of this series showed brittle mode of failure with the inability to hold load after ultimate failure had occurred. When crushing was observed almost spreaded over the entire length of the specimen, strains at failure were found to be quite small compared to those observed for the other reinforced specimen of this study.

5.2 SPECIMEN SET ACI:

This set was tested with one, two and three load cycles. For one cycle loading strain was about 2.5% at maximum load, whereas with the increased cycles the corresponding strain became higher. This is due to the residual strain occurred

table 5.1. SUMMARY OF THE TEST RESULTS.

SPECIMEN:CYLINDERS, SET:PCC, CUBE STRENGTH: 26.03 MPa.

SNo	DESCRIPTION / SPECIMEN ->		PCC1	PCC2	PCC	PCC4
i>	PHYSICAL OBSERVATIONS:					
1.	HEIGHT	mm.	307	306	307	306
2.	DIAMETRE	mm.	152	153	153	152
3.	AREA OF X-SECTION	sq.mm.	18153.1	18392.8	18392.8	18153.1
4.	VOLUME	cu.cm.	5573.01	5628.19	5646.59	5554.86
5.	WEIGHT	N.	131.85	130.60	132.55	134.05
6.	DENSITY	kN/cu.m.	23.66	23.20	23.47	24.13
7.	AGE AT TESTING	days.	44	45	28	41
ii>	LOADING OBSERVATIONS:					
1.	No. OF LOAD CYCLES	#.	2	2	1	2
2.	LOAD AT CRACKING	kN.	300	280	280	290
3.	ULTIMATE LOAD TAKEN	kN.	300	310	240	320
4.	STRESS AT ULTIMATE	MPa.	16.53	16.85	13.05	17.63
5.	STRAIN AT CRACKING	%	0.4	0.21	0.263	0.22
6.	STRAIN AT ULTIMATE LOAD	%	0.4	0.86	0.42	0.335

SPECIMEN:CYLINDERS, SET:ACI, CUBE STRENGTH: 23.95 MPa.

SNo	DESCRIPTION / SPECIMEN ->		ACI1	ACI	ACI
i>	PHYSICAL OBSERVATIONS:				
1.	HEIGHT	mm.	308	309	310
2.	DIAMETRE	mm.	152	152	154
3.	AREA OF X-SECTION	sq.mm.	18153.1	18153.1	18634.0
4.	VOLUME	cu.cm.	5591.17	5609.32	5776.54
5.	WEIGHT	N.	135.00	135.20	136.19
6.	DENSITY	kN/cu.m.	24.15	24.10	23.58
7.	AGE AT TESTING	days.	52	45	52
ii>	LOADING OBSERVATIONS:				
1.	No. OF LOAD CYCLES	#.	3	2	1
2.	LOAD AT CRACKING	kN.	400	390	380
3.	ULTIMATE LOAD TAKEN	kN.	520	570	550
4.	STRESS AT ULTIMATE	MPa.	28.65	31.40	29.52
5.	STRAIN AT CRACKING	%	0.705	0.75	0.4675
6.	STRAIN AT COVER FAILED	%	2.005	1.735	1.3425
7.	STRAIN AT SPIRAL FAILED	%	2.98	2.035	2.5675
8.	STRAIN AT ULTIMATE LOAD	%	4.03	4.435	2.5675

TABLE 5·1 (Contd)

SPECIMEN:CYLINDERS, SET:ISS, CUBE STRENGTH: 23.95 MPa.

SNo	DESCRIPTION/SPECIMEN ->		ISS1	ISS2	ISS3
i>	PHYSICAL OBSERVATIONS:				
1.	HEIGHT	mm.	306	306	307
2.	DIAMETRE	mm.	154	155	155
3.	AREA OF X-SECTION	sq.mm.	18634.0	18876.8	18876.8
4.	VOLUME	cu.cm.	5702.00	5776.30	5795.17
5.	WEIGHT	N.	135.72	133.60	135.68
6.	DENSITY	kN/cu.m.	23.80	23.13	23.41
7.	AGE AT TESTING	days.	64	56	63
ii>	LOADING OBSERVATIONS:				
1.	No. OF LOAD CYCLES	#.	5	3	4
2.	LOAD AT CRACKING	kN.	420	360	420
3.	ULTIMATE LOAD TAKEN	kN.	500	432.5	500
4.	STRESS AT ULTIMATE	MPa.	26.8326	22.9117	26.4875
5.	STRAIN AT CRACKING	%	0.5591	0.5202	0.7409
6.	STRAIN AT COVER FAILED	%	1.6045	1.1886	1.7318
7.	STRAIN AT SPIRAL FAILED	%	2.8773	2.0341	2.6409
8.	STRAIN AT ULTIMATE LOAD	%	1.9227	2.0341	2.6409

Table 5.1 (continued)

SPECIMEN:CYLINDERS, SET:ISF, CUBE STRENGTH: MPa.

SNo	DESCRIPTION/ SPECIMEN -		ISF	ISF	ISF	HFC
i	PHYSICAL OBSERVATIONS:					
1.	HEIGHT	mm.	306	306	307	307
2.	DIAMETRE	mm.	153	153	153	154
3.	AREA OF X-SECTION	sq.mm.	18392.8	18392.8	18392.8	18634.0
4.	VOLUME	cu.cm.	5628.2	5628.2	5646.6	5720.6
5.	WEIGHT	N.	120.55	109.00	114.95	123.52
6.	DENSITY	kN/cu.m.	21.42	19.37	20.36	21.59
7.	AGE AT TESTING	days.				
ii	LOADING OBSERVATIONS:					
1.	No. OF LOAD CYCLES	#.	4	3	2	1
2.	LOAD AT CRACKING	kN.	240	190	182.5	220
3.	ULTIMATE LOAD TAKEN	kN.	390	202.5	192.5	260
4.	STRESS AT ULTIMATE	MPa.	21.20	11.01	10.47	13.95
5.	STRAIN AT CRACKING %		0.367	3.080	3.392	0.520
6.	STRAIN AT COVER FAILED		0.552	3.502	4.218	1.315
7.	STRAIN AT SPIRAL FAILED		1.277	3.755	9.932	3.455
8.	STRAIN AT ULTIMATE LOAD		1.547	3.755	7.380	3.053

SPECIMEN:CYLINDERS, SET:RSF. CUBE STRENGTH: MPa.

SNo	DESCRIPTION/ SPECIMEN -		RSF1	RSF2	RSF3	PFC
i	PHYSICAL OBSERVATIONS:					
1.	HEIGHT	mm.	304	305	306	307
2.	DIAMETRE	mm.	153	152	154	153
3.	AREA OF X-SECTION	sq.mm.	18392.8	18153.1	18634.0	18392.8
4.	VOLUME	cu.cm.	5591.41	5536.71	5702.00	5646.59
5.	WEIGHT	N.	118.40	106.20	114.12	125.13
6.	DENSITY	kN/cu.m.	21.18	19.18	20.01	22.16
7.	AGE AT TESTING	days.				
ii	LOADING OBSERVATIONS:					
1.	No. OF LOAD CYCLES	#.	2	2	3	2
2.	LOAD AT CRACKING	kN.	160	200	240	220
3.	ULTIMATE LOAD TAKEN	kN.	175	215.5	270	240
4.	STRESS AT ULTIMATE	MPa.	9.51	11.87	14.49	13.05
5.	STRAIN AT CRACKING		0.4317	0.4183	0.405	0.2208
6.	STRAIN AT ULTIMATE LOAD		0.5565	0.885	0.8533	0.4925

Table 5.1 (continued)

SPECIMEN: CUBES, SET 1 CUBE STRENGTH: MPa.

SNo	DESCRIPTION/ SPECIMEN -		1D	1E	1F
i)	PHYSICAL OBSERVATIONS:				
1.	HEIGHT	mm.	150.00	150.00	151.00
2.	LENGTH	mm.	150.00	150.00	154.00
3.	BREADTH	mm.	150.00	150.00	152.00
4.	AREA OF X-SECTION	sq.mm.	22500.0	22500.0	23408.0
5.	VOLUME	cu.cm.	3375.00	3375.00	3534.61
6.	WEIGHT	N.	81.75	81.30	86.45
7.	DENSITY	kN/cu.m.	24.22	24.09	24.46
8.	AGE AT TESTING	days.	70	70	70
ii)	LOADING OBSERVATIONS:				
1.	No. OF LOAD CYCLES	#.	1.00	1.00	1.00
2.	LOAD AT CRACKING	kN.			
3.	ULTIMATE LOAD TAKEN	kN.	56.00	53.00	54.75
4.	STRESS AT ULTIMATE	MPa.	24.89	23.56	23.39

SPECIMEN: CUBES, SET 2 CUBE STRENGTH: MPa.

SNo	DESCRIPTION/ SPECIMEN -		2D	2E	2F
i)	PHYSICAL OBSERVATIONS:				
1.	HEIGHT	mm.	155.00	150.00	150.00
2.	LENGTH	mm.	154.00	152.00	151.00
3.	BREADTH	mm.	153.00	151.00	151.00
4.	AREA OF X-SECTION	sq.mm.	23562.0	22952.0	22801.0
5.	VOLUME	cu.cm.	3652.11	3442.80	3420.15
6.	WEIGHT	N.	88.05	84.35	81.55
7.	DENSITY	kN/cu.m.	24.11	24.50	23.84
8.	AGE AT TESTING	days.	72	66	66
ii)	LOADING OBSERVATIONS:				
1.	No. OF LOAD CYCLES	#.	1.00	1.00	1.00
2.	LOAD AT CRACKING	kN.	45.00		
3.	ULTIMATE LOAD TAKEN	kN.	62.00	64.00	54.50
4.	STRESS AT ULTIMATE	MPa.	26.31	27.88	23.90

after each cycle. The tests with multiple loading cycles reasonably simulate the actual loading conditions of real-life structures.

For compacting and vibrating the specimens during casting, tamping bar and needle vibrator were used. This led to unequal compaction in the same set of specimens, as verified by the concrete densities of different samples determined after curing.

In general due to the decrease in the number of load cycles, ultimate load carrying capacity should increase for the same strains. But in the case of ACI6, the ultimate load decreased compared to those of ACI1 and ACI3. This is probably due to the fact that density of ACI6 was less then that of ACI1 and ACI3. This may be attributed to the method of compaction adopted during specimen preparation. Hence methods are to be employed to give uniform compaction in all the specimens.

At near failure loads, it was found difficult to keep the load at a constant value to measure the plastic deformation. However all efforts were made and the best possible observations showed that spiral confined column demonstrated some amount of load maintaining capacity with excessive deformations at or near maximum load condition.

In all the three specimens covers became separate from core at some places along the length of the specimen at a strain of about 0.4% and followed by some load drops. But the

covers were in place till the strains reached about 1%. Loads on the specimens started increasing again at this stage. This maybe due to the spirals coming into action. Covers spalled off completely before a strain of 2%, subsequently the core was subjected to lateral confining pressures by spirals only. The spirals failed at some point during the process of lateral bulging of the concrete.

In ACI3 and ACI6, spirals were provided outside the vertical supporting bars and thus the verticals were prevented from buckling due to compressive load. In both of these cases failure was initiated by the failure of spiral at minimum core diameter, followed by crushing of unconfined concrete at the places of spiral-failure and subsequently the specimens bent towards the direction of spiral failure.

In ACI1 the verticals were placed outside the spiral to see the effect. In this case failure was initiated by the buckling of two verticals successively and no load drop was observed at this stage till the spiral failed in tension. This is possibly due to the fact that the verticals contributed negligibly towards the load carrying capacity. Other observations were similar to the rest of the specimens in this set

5.3 SPECIMEN SET ISS:

This set of specimens were tested with three, four and five loading cycles. For all the specimens negligibly small residual strains of the order of 0.0001 were observed in the

first loading cycle indicating that the loading occurred in the elastic range. The subsequent load-cycles produced residual strains having increasing trend.

Spirals played role in confining the concrete effectively, came into action when the cover started cracking from the core.

The covers of the specimens were found separated from the core concrete at some locations over the length of the specimens at a strain of about 0.5 to 0.75 percent followed by slight load drops. When the process of cover separation was basically over, the specimen started carrying increasing loads till the spirals failed.

Two of the specimens (ISS2 and ISS3) could be tested upto ultimate only, showed large strains in the range of 1.0 to 2.0 percent with the inability to carry much load after spiral failed.

5.4 SPECIMEN SET ISF:

Failure patterns of ISF set of specimens were observed to be similar to those of ISS set except that the cover concrete was held in place due to the presence of fibers.

Initially the fibers helped in providing additional ductility to the core concrete. In this process the fibers may yield with increasing strain till the strength of the fibrous matrix is fully utilized and then the spirals came into action for providing confining pressures to the core concrete. This combined effect enhanced the ductility properties of the specimens.

5.5 SPECIMEN SET RFC:

In this set due to the reduced confining pressure by the spiral (spiral volume is least among all the sets of specimens), maximum load was less for all the three specimens RFC1, RFC2 and RFC3. But both spirals and fibers contributed to ductility and showed load maintaining capacity (about 70% of the maximum load of respective specimens) for strains upto the range of 10 to 12 percent, even after spiral failure of one or two spirals. The shortening was mainly due to crushing of unconfined concrete at the failed spiral locations.

5.6 SPECIMEN HFC:

In this specimen, circular hoops were provided instead of spirals with anchorage provisions conforming the IS code [2]. During the testing of this specimen, at near failure load, the hoop at the center of the specimen started opening. The load was almost constant at this point. Once the hoop came out completely, the load started decreasing. This showed that the anchorage provided may not be adequate to get full strength for confining the core.

5.7 SPECIMEN PFC:

In this specimen the fibers prevented spalling of concrete from the outer surface of the specimen but did not contribute to the ductility. Excessive shortening was observed which may be due to bulging of the specimen.

6. SUMMARY AND CONCLUSIONS.

The present study was aimed to study the ductility behavior of plain and fibrous concrete specimens with lateral spiral reinforcements subjected to axial loading. To achieve this various types of specimens were prepared according to the specifications of ACI and IS codes and tested in different number of load cycles

From the observations and test results, the following salient points are presented along with the conclusions of the present study and scope for further investigation.

6.1 SUMMARY:

Plain cement concrete specimens showed load carrying capacity at relatively low strains and beyond the ultimate point concrete spalled off from the outer surface due to internal cracking. This phenomenon caused the catastrophic failure with sudden load drops.

Among the specimens present in this study, ACI specimens contained highest spiral volume. These specimens showed continuous increase in the load carrying capacity till the spirals failed. At this stage load dropped and crushing of concrete started. As the pitch of the spirals is minimum in these specimens the crushing of concrete was minimum. The disadvantage of the smaller spiral spacing was identified in the cover separation phase; the cover concrete fell apart in

big lumps due to the induced failure surface along the cylindrical surface of spiral.

The ISS specimens showed load carrying capacity after spirals were failed but crushing of concrete at the failed spiral location was observed to be predominant. This led to load drop and differential settlement of the specimens.

The ISF set contained the amount of spiral as of ISS but the presence of fibers enhanced the ductility properties. Fibers helped in keeping the cover in place and prevented the crushing of concrete to some extent after spiral failure. Only at a very few locations where concrete crushed, fibers became loose and came out with cover concrete.

The RFC set contained the least amount of spiral volume along with fibers. This set demonstrated considerably good load carrying capacity at very high strains of the order of 10 to 12 percent. Load drops were also present just after spiral failure, which has been observed to be the phenomenon in all the cases of this study. This load drop immediately after the spiral failure did not affect the load carrying capacity adversely as it is evident from the test results. Presence of fibers influenced the ductility behavior and the failure patterns were in the ways similar to the ISF set.

6.2 CONCLUSIONS:

Based on the experiences gathered from the present study, following conclusions have been reached.

1. Relatively higher volume of the spiral reinforcements as specified in relevant ACI code [1] may be provided on a selective basis when the structure demands additional ductility requirements.

2. For small size columns the diameter of spiral reinforcements should preferably be larger to the extent possible considering other factors e.g. ease of working etc. in order to minimize the possibility of relatively easier separation of cover concrete portions from the core.

3. For large size columns the diameter of spiral reinforcements should preferably be on the lower side to prevent excessive crushing after the yielding and failure of the spirals.

4. The spiral volume as recommended in the relevant IS code [2] appeared to be on the lower side. This provision should be reviewed to come up with higher volume of spiral reinforcements in order to achieve better load-sustaining behavior in the post-spiral failure stage.

5. To meet higher ductility requirements, fibrous concrete may be adopted for spiral reinforced column.

6. The volume of spiral reinforcements as recommended in IS code [2] should be reviewed to decrease the volume of spirals in cases of fibrous concrete.

6.3 SCOPE FOR FURTHER INVESTIGATIONS:

Further investigations may be taken up in the following areas to come up with better ductility data.

a) In the area of spiral confined concrete to study the effects of

-concrete grades

-grade of steel and

-shape of cross section.

b) Full scale testing of fibrous concrete columns may be undertaken to get the more realistic research data on the ductility.

c) Investigations on columns with two or more interlinked spirals coming up and

d) Investigations on columns of plain and fibrous concrete with prestressed spirals.

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